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T. Haynes, Ed.
NetApp
D. Noveck, Ed.
EMC

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Network File System (NFS) Version 4 Protocol
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Abstract

The Network File System (NFS) version 4 is a distributed filesystem protocol which owes heritage to NFS protocol version 2, RFC 1094, and version 3, RFC 1813. Unlike earlier versions, the NFS version 4 protocol supports traditional file access while integrating support for file locking and the mount protocol. In addition, support for strong security (and its negotiation), compound operations, client caching, and internationalization have been added. Of course, attention has been applied to making NFS version 4 operate well in an Internet environment.

This document, together with the companion XDR description document, RFCNFSv4XDR, replaces RFC 3530 as the definition of the NFS version 4 protocol.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [1].

Status of this Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on May 14, 2013.

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1. Introduction

1.1. Changes since RFC 3530

This document, together with the companion XDR description document [2], obsoletes RFC 3530 [11] as the authoritative document describing NFSv4. It does not introduce any over-the-wire protocol changes, in the sense that previously valid requests requests remain valid. However, some requests previously defined as invalid, although not generally rejected, are now explicitly allowed, in that internationalization handling has been generalized and liberalized. The main changes from RFC 3530 are:

- The XDR definition has been moved to a companion document [2]
- Updates for the latest IETF intellectual property statements
- There is a restructured and more complete explanation of multi-server namespace features. In particular, this explanation explicitly describes handling of inter-server referrals, even where neither migration nor replication is involved.
- More liberal handling of internationalization for file names and user and group names, with the elimination of restrictions imposed by stringprep, with the recognition that rules for the forms of these name are the province of the receiving entity.
- Updating handling of domain names to reflect IDNA [3].
- Restructuring of string types to more appropriately reflect the reality of required string processing.
- The previously required LIPKEY and SPKM-3 security mechanisms have been removed.
- Some clarification on a client re-establishing callback information to the new server if state has been migrated.
- A third edge case was added for Courtesy locks and network partitions.
- The definition of stateid was strengthened.

1.2. Changes since RFC 3010

This definition of the NFSv4 protocol replaces or obsoletes the definition present in [12]. While portions of the two documents have remained the same, there have been substantive changes in others.

The changes made between [12] and this document represent implementation experience and further review of the protocol. While some modifications were made for ease of implementation or clarification, most updates represent errors or situations where the [12] definition were untenable.

The following list is not all inclusive of all changes but presents some of the most notable changes or additions made:

- The state model has added an open_owner4 identifier. This was done to accommodate Posix based clients and the model they use for file locking. For Posix clients, an open_owner4 would correspond to a file descriptor potentially shared amongst a set of processes and the lock_owner4 identifier would correspond to a process that is locking a file.

- Clarifications and error conditions were added for the handling of the owner and group attributes. Since these attributes are string based (as opposed to the numeric uid/gid of previous versions of NFS), translations may not be available and hence the changes made.

- Clarifications for the ACL and mode attributes to address evaluation and partial support.

- For identifiers that are defined as XDR opaque, limits were set on their size.

- Added the mounted_on_filed attribute to allow Posix clients to correctly construct local mounts.

- Modified the SETCLIENTID/SETCLIENTID_CONFIRM operations to deal correctly with confirmation details along with adding the ability to specify new client callback information. Also added clarification of the callback information itself.

- Added a new operation RELEASE_LOCKOWNER to enable notifying the server that a lock_owner4 will no longer be used by the client.

- RENEW operation changes to identify the client correctly and allow for additional error returns.

- Verify error return possibilities for all operations.

- Remove use of the pathname4 data type from LOOKUP and OPEN in favor of having the client construct a sequence of LOOKUP operations to achieve the same effect.

- Clarification of the internationalization issues and adoption of the new stringprep profile framework.

1.3. NFS Version 4 Goals

The NFSv4 protocol is a further revision of the NFS protocol defined already by versions 2 [13] and 3 [14]. It retains the essential characteristics of previous versions: design for easy recovery, independent of transport protocols, operating systems and filesystems, simplicity, and good performance. The NFSv4 revision has the following goals:

- Improved access and good performance on the Internet.

  The protocol is designed to transit firewalls easily, perform well where latency is high and bandwidth is low, and scale to very large numbers of clients per server.

- Strong security with negotiation built into the protocol.

  The protocol builds on the work of the ONCRPC working group in supporting the RPCSEC_GSS protocol. Additionally, the NFS version 4 protocol provides a mechanism to allow clients and servers the ability to negotiate security and require clients and servers to support a minimal set of security schemes.

- Good cross-platform interoperability.

  The protocol features a filesystem model that provides a useful, common set of features that does not unduly favor one filesystem or operating system over another.

- Designed for protocol extensions.

  The protocol is designed to accept standard extensions that do not compromise backward compatibility.

1.4. Inconsistencies of this Document with the companion document NFS Version 4 Protocol

[2], NFS Version 4 Protocol, contains the definitions in XDR description language of the constructs used by the protocol. Inside this document, several of the constructs are reproduced for purposes of explanation. The reader is warned of the possibility of errors in the reproduced constructs outside of [2]. For any part of the document that is inconsistent with [2], [2] is to be considered authoritative.

1.5. Overview of NFSv4 Features

To provide a reasonable context for the reader, the major features of NFSv4 protocol will be reviewed in brief. This will be done to provide an appropriate context for both the reader who is familiar with the previous versions of the NFS protocol and the reader that is new to the NFS protocols. For the reader new to the NFS protocols, some fundamental knowledge is still expected. The reader should be familiar with the XDR and RPC protocols as described in [4] and [15]. A basic knowledge of filesystems and distributed filesystems is expected as well.

1.5.1. RPC and Security

As with previous versions of NFS, the External Data Representation (XDR) and Remote Procedure Call (RPC) mechanisms used for the NFSv4 protocol are those defined in [4] and [15]. To meet end to end security requirements, the RPCSEC_GSS framework [5] will be used to extend the basic RPC security. With the use of RPCSEC_GSS, various mechanisms can be provided to offer authentication, integrity, and privacy to the NFS version 4 protocol. Kerberos V5 will be used as described in [16] to provide one security framework. With the use of RPCSEC_GSS, other mechanisms may also be specified and used for NFS version 4 security.

To enable in-band security negotiation, the NFSv4 protocol has added a new operation which provides the client a method of querying the server about its policies regarding which security mechanisms must be used for access to the server's filesystem resources. With this, the client can securely match the security mechanism that meets the policies specified at both the client and server.

1.5.2. Procedure and Operation Structure

A significant departure from the previous versions of the NFS protocol is the introduction of the COMPOUND procedure. For the NFSv4 protocol, there are two RPC procedures, NULL and COMPOUND. The COMPOUND procedure is defined in terms of operations and these operations correspond more closely to the traditional NFS procedures.

With the use of the COMPOUND procedure, the client is able to build simple or complex requests. These COMPOUND requests allow for a reduction in the number of RPCs needed for logical filesystem operations. For example, without previous contact with a server a client will be able to read data from a file in one request by combining LOOKUP, OPEN, and READ operations in a single COMPOUND RPC. With previous versions of the NFS protocol, this type of single request was not possible.

The model used for COMPOUND is very simple. There is no logical OR or ANDing of operations. The operations combined within a COMPOUND request are evaluated in order by the server. Once an operation returns a failing result, the evaluation ends and the results of all evaluated operations are returned to the client.

The NFSv4 protocol continues to have the client refer to a file or directory at the server by a "filehandle". The COMPOUND procedure has a method of passing a filehandle from one operation to another within the sequence of operations. There is a concept of a "current filehandle" and "saved filehandle". Most operations use the "current filehandle" as the filesystem object to operate upon. The "saved filehandle" is used as temporary filehandle storage within a COMPOUND procedure as well as an additional operand for certain operations.

1.5.3. Filesystem Model

The general filesystem model used for the NFSv4 protocol is the same as previous versions. The server filesystem is hierarchical with the regular files contained within being treated as opaque byte streams. In a slight departure, file and directory names are encoded with UTF-8 to deal with the basics of internationalization.

The NFSv4 protocol does not require a separate protocol to provide for the initial mapping between path name and filehandle. Instead of using the older MOUNT protocol for this mapping, the server provides a ROOT filehandle that represents the logical root or top of the filesystem tree provided by the server. The server provides multiple filesystems by gluing them together with pseudo filesystems. These pseudo filesystems provide for potential gaps in the path names between real filesystems.

1.5.3.1. Filehandle Types

In previous versions of the NFS protocol, the filehandle provided by the server was guaranteed to be valid or persistent for the lifetime of the filesystem object to which it referred. For some server implementations, this persistence requirement has been difficult to meet. For the NFSv4 protocol, this requirement has been relaxed by introducing another type of filehandle, volatile. With persistent and volatile filehandle types, the server implementation can match the abilities of the filesystem at the server along with the operating environment. The client will have knowledge of the type of filehandle being provided by the server and can be prepared to deal with the semantics of each.

1.5.3.2. Attribute Types

The NFSv4 protocol has a rich and extensible file object attribute structure, which is divided into REQUIRED, RECOMMENDED, and named attributes (see Section 5).

Several (but not all) of the REQUIRED attributes are derived from the attributes of NFSv3 (see definition of the fattr3 data type in [14]). An example of a REQUIRED attribute is the file object's type (Section 5.8.1.2) so that regular files can be distinguished from directories (also known as folders in some operating environments) and other types of objects. REQUIRED attributes are discussed in Section 5.1.

An example of the RECOMMENDED attributes is an acl. This attribute defines an Access Control List (ACL) on a file object ((Section 6). An ACL provides file access control beyond the model used in NFSv3. The ACL definition allows for specification of specific sets of permissions for individual users and groups. In addition, ACL inheritance allows propagation of access permissions and restriction down a directory tree as file system objects are created. RECOMMENDED attributes are discussed in Section 5.2.

A named attribute is an opaque byte stream that is associated with a directory or file and referred to by a string name. Named attributes are meant to be used by client applications as a method to associate application-specific data with a regular file or directory. NFSv4.1 modifies named attributes relative to NFSv4.0 by tightening the allowed operations in order to prevent the development of non-interoperable implementations. Named attributes are discussed in Section 5.3.

1.5.3.3. Multi-server Namespace

NFSv4 contains a number of features to allow implementation of namespaces that cross server boundaries and that allow and facilitate a non-disruptive transfer of support for individual file systems between servers. They are all based upon attributes that allow one file system to specify alternate or new locations for that file system.

These attributes may be used together with the concept of absent file systems, which provide specifications for additional locations but no actual file system content. This allows a number of important facilities:

- Location attributes may be used with absent file systems to implement referrals whereby one server may direct the client to a

file system provided by another server. This allows extensive multi-server namespaces to be constructed.

- Location attributes may be provided for present file systems to provide the locations of alternate file system instances or replicas to be used in the event that the current file system instance becomes unavailable.

- Location attributes may be provided when a previously present file system becomes absent. This allows non-disruptive migration of file systems to alternate servers.

1.5.4. OPEN and CLOSE

The NFSv4 protocol introduces OPEN and CLOSE operations. The OPEN operation provides a single point where file lookup, creation, and share semantics can be combined. The CLOSE operation also provides for the release of state accumulated by OPEN.

1.5.5. File Locking

With the NFSv4 protocol, the support for byte range file locking is part of the NFS protocol. The file locking support is structured so that an RPC callback mechanism is not required. This is a departure from the previous versions of the NFS file locking protocol, Network Lock Manager (NLM). The state associated with file locks is maintained at the server under a lease-based model. The server defines a single lease period for all state held by a NFS client. If the client does not renew its lease within the defined period, all state associated with the client's lease may be released by the server. The client may renew its lease with use of the RENEW operation or implicitly by use of other operations (primarily READ).

1.5.6. Client Caching and Delegation

The file, attribute, and directory caching for the NFSv4 protocol is similar to previous versions. Attributes and directory information are cached for a duration determined by the client. At the end of a predefined timeout, the client will query the server to see if the related filesystem object has been updated.

For file data, the client checks its cache validity when the file is opened. A query is sent to the server to determine if the file has been changed. Based on this information, the client determines if the data cache for the file should kept or released. Also, when the file is closed, any modified data is written to the server.

If an application wants to serialize access to file data, file

locking of the file data ranges in question should be used.

The major addition to NFSv4 in the area of caching is the ability of the server to delegate certain responsibilities to the client. When the server grants a delegation for a file to a client, the client is guaranteed certain semantics with respect to the sharing of that file with other clients. At OPEN, the server may provide the client either a OPEN_DELEGATE_READ or OPEN_DELEGATE_WRITE delegation for the file. If the client is granted a OPEN_DELEGATE_READ delegation, it is assured that no other client has the ability to write to the file for the duration of the delegation. If the client is granted a OPEN_DELEGATE_WRITE delegation, the client is assured that no other client has read or write access to the file.

Delegations can be recalled by the server. If another client requests access to the file in such a way that the access conflicts with the granted delegation, the server is able to notify the initial client and recall the delegation. This requires that a callback path exist between the server and client. If this callback path does not exist, then delegations cannot be granted. The essence of a delegation is that it allows the client to locally service operations such as OPEN, CLOSE, LOCK, LOCKU, READ, or WRITE without immediate interaction with the server.

1.6. General Definitions

The following definitions are provided for the purpose of providing an appropriate context for the reader.

Byte: In this document, a byte is an octet, i.e., a datum exactly 8 bits in length.

Client: The client is the entity that accesses the NFS server's resources. The client may be an application that contains the logic to access the NFS server directly. The client may also be the traditional operating system client that provides remote filesystem services for a set of applications.

With reference to byte-range locking, the client is also the entity that maintains a set of locks on behalf of one or more applications. This client is responsible for crash or failure recovery for those locks it manages.

Note that multiple clients may share the same transport and connection and multiple clients may exist on the same network node.

Client ID: A 64-bit quantity used as a unique, short-hand reference to a client supplied Verifier and ID. The server is responsible for supplying the Client ID.

File System: The file system is the collection of objects on a server that share the same fsid attribute (see Section 5.8.1.9).

Lease: An interval of time defined by the server for which the client is irrevocably granted a lock. At the end of a lease period the lock may be revoked if the lease has not been extended. The lock must be revoked if a conflicting lock has been granted after the lease interval.

All leases granted by a server have the same fixed interval. Note that the fixed interval was chosen to alleviate the expense a server would have in maintaining state about variable length leases across server failures.

Lock: The term "lock" is used to refer to both record (byte-range) locks as well as share reservations unless specifically stated otherwise.

Server: The "Server" is the entity responsible for coordinating client access to a set of filesystems.

Stable Storage: NFSv4 servers must be able to recover without data loss from multiple power failures (including cascading power failures, that is, several power failures in quick succession), operating system failures, and hardware failure of components other than the storage medium itself (for example, disk, nonvolatile RAM).

Some examples of stable storage that are allowable for an NFS server include:

(1) Media commit of data, that is, the modified data has been successfully written to the disk media, for example, the disk platter.

(2) An immediate reply disk drive with battery-backed on-drive intermediate storage or uninterruptible power system (UPS).

(3) Server commit of data with battery-backed intermediate storage and recovery software.

(4) Cache commit with uninterruptible power system (UPS) and recovery software.

Stateid: A stateid is a 128-bit quantity returned by a server that uniquely identifies the open and locking states provided by the server for a specific open-owner or lock-owner/open-owner pair for a specific file and type of lock.

Verifier: A 64-bit quantity generated by the client that the server can use to determine if the client has restarted and lost all previous lock state.

2. Protocol Data Types

The syntax and semantics to describe the data types of the NFS version 4 protocol are defined in the XDR [15] and RPC [4] documents. The next sections build upon the XDR data types to define types and structures specific to this protocol.

2.1. Basic Data Types

These are the base NFSv4 data types.

Data Type	Definition
int32_t	typedef int int32_t;
uint32_t	typedef unsigned int uint32_t;
int64_t	typedef hyper int64_t;
uint64_t	typedef unsigned hyper uint64_t;
attrlist4	typedef opaque attrlist4<>; Used for file/directory attributes.
bitmap4	typedef uint32_t bitmap4<>; Used in attribute array encoding.
changeid4	typedef uint64_t changeid4; Used in the definition of change_info4.
clientid4	typedef uint64_t clientid4; Shorthand reference to client identification.
count4	typedef uint32_t count4; Various count parameters (READ, WRITE, COMMIT).
length4	typedef uint64_t length4; Describes LOCK lengths.
mode4	typedef uint32_t mode4; Mode attribute data type.
nfs_cookie4	typedef uint64_t nfs_cookie4;

	Opaque cookie value for READDIR.
nfs_fh4	typedef opaque nfs_fh4<NFS4_FHSIZE>; Filehandle definition.
nfs_ftype4	enum nfs_ftype4; Various defined file types.
nfsstat4	enum nfsstat4; Return value for operations.
offset4	typedef uint64_t offset4; Various offset designations (READ, WRITE, LOCK, COMMIT).
qop4	typedef uint32_t qop4; Quality of protection designation in SECINFO.
sec_oid4	typedef opaque sec_oid4<>; Security Object Identifier. The sec_oid4 data type is not really opaque. Instead it contains an ASN.1 OBJECT IDENTIFIER as used by GSS-API in the mech_type argument to GSS_Init_sec_context. See [6] for details.
seqid4	typedef uint32_t seqid4; Sequence identifier used for file locking.
utf8string	typedef opaque utf8string<>; UTF-8 encoding for strings.
utf8_expected	typedef utf8string utf8_expected; String expected to be UTF-8 but no validation
utf8val_RECOMMENDED4	typedef utf8string utf8val_RECOMMENDED4; String SHOULD be sent UTF-8 and SHOULD be validated
utf8val_REQUIRED4	typedef utf8string utf8val_REQUIRED4; String MUST be sent UTF-8 and MUST be validated
ascii_REQUIRED4	typedef utf8string ascii_REQUIRED4; String MUST be sent as ASCII and thus is automatically UTF-8
comptag4	typedef utf8_expected comptag4; Tag should be UTF-8 but is not checked
component4	typedef utf8val_RECOMMENDED4 component4; Represents path name components.
linktext4	typedef utf8val_RECOMMENDED4 linktext4; Symbolic link contents.
pathname4	typedef component4 pathname4<>; Represents path name for fs_locations.
nfs_lockid4	typedef uint64_t nfs_lockid4;
verifier4	typedef opaque verifier4[NFS4_VERIFIER_SIZE];

		Verifier used for various operations (COMMIT, CREATE, OPEN, READDIR, WRITE) NFS4_VERIFIER_SIZE is defined as 8.

End of Base Data Types

Table 1

2.2. Structured Data Types

2.2.1. nfstime4

```
struct nfstime4 {
        int64_t         seconds;
        uint32_t        nseconds;
};
```

The nfstime4 structure gives the number of seconds and nanoseconds since midnight or 0 hour January 1, 1970 Coordinated Universal Time (UTC). Values greater than zero for the seconds field denote dates after the 0 hour January 1, 1970. Values less than zero for the seconds field denote dates before the 0 hour January 1, 1970. In both cases, the nseconds field is to be added to the seconds field for the final time representation. For example, if the time to be represented is one-half second before 0 hour January 1, 1970, the seconds field would have a value of negative one (-1) and the nseconds fields would have a value of one-half second (500000000). Values greater than 999,999,999 for nseconds are considered invalid.

This data type is used to pass time and date information. A server converts to and from its local representation of time when processing time values, preserving as much accuracy as possible. If the precision of timestamps stored for a filesystem object is less than defined, loss of precision can occur. An adjunct time maintenance protocol is recommended to reduce client and server time skew.

2.2.2. time_how4

```
enum time_how4 {
        SET_TO_SERVER_TIME4 = 0,
        SET_TO_CLIENT_TIME4 = 1
};
```

2.2.3. settime4

```
union settime4 switch (time_how4 set_it) {
 case SET_TO_CLIENT_TIME4:
         nfstime4       time;
 default:
         void;
};
```

The above definitions are used as the attribute definitions to set time values. If set_it is SET_TO_SERVER_TIME4, then the server uses its local representation of time for the time value.

2.2.4. specdata4

```
struct specdata4 {
 uint32_t specdata1; /* major device number */
 uint32_t specdata2; /* minor device number */
};
```

This data type represents additional information for the device file types NF4CHR and NF4BLK.

2.2.5. fsid4

```
struct fsid4 {
        uint64_t        major;
        uint64_t        minor;
};
```

This type is the filesystem identifier that is used as a mandatory attribute.

2.2.6. fs_location4

```
struct fs_location4 {
        utf8val_REQUIRED4       server<>;
        pathname4               rootpath;
};
```

2.2.7. fs_locations4

```
struct fs_locations4 {
        pathname4       fs_root;
        fs_location4    locations<>;
};
```

The fs_location4 and fs_locations4 data types are used for the

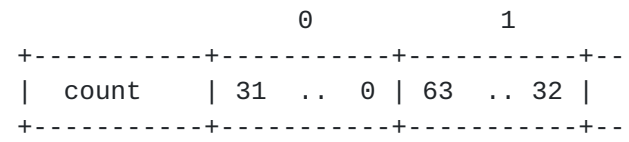
fs_locations recommended attribute which is used for migration and replication support.

2.2.8. fattr4

```
struct fattr4 {
        bitmap4         attrmask;
        attrlist4       attr_vals;
};
```

The fattr4 structure is used to represent file and directory attributes.

The bitmap is a counted array of 32 bit integers used to contain bit values. The position of the integer in the array that contains bit n can be computed from the expression (n / 32) and its bit within that integer is (n mod 32).



2.2.9. change_info4

```
struct change_info4 {
        bool            atomic;
        changeid4       before;
        changeid4       after;
};
```

This structure is used with the CREATE, LINK, REMOVE, RENAME operations to let the client know the value of the change attribute for the directory in which the target filesystem object resides.

2.2.10. clientaddr4

```
struct clientaddr4 {
        /* see struct rpcb in RFC 1833 */
        string r_netid<>;    /* network id */
        string r_addr<>;     /* universal address */
};
```

The clientaddr4 structure is used as part of the SETCLIENTID operation to either specify the address of the client that is using a client ID or as part of the callback registration. The r_netid and r_addr fields respectively contain a netid and uaddr. The netid and

uaddr concepts are defined in [7]. The netid and uaddr formats for TCP over IPv4 and TCP over IPv6 are defined in [7], specifically Tables 2 and 3 and Sections 5.2.3.3 and 5.2.3.4.

2.2.11. cb_client4

```
struct cb_client4 {
        unsigned int    cb_program;
        clientaddr4     cb_location;
};
```

This structure is used by the client to inform the server of its call back address; includes the program number and client address.

2.2.12. nfs_client_id4

```
struct nfs_client_id4 {
        verifier4       verifier;
        opaque          id<NFS4_OPAQUE_LIMIT>;
};
```

This structure is part of the arguments to the SETCLIENTID operation. NFS4_OPAQUE_LIMIT is defined as 1024.

2.2.13. open_owner4

```
struct open_owner4 {
        clientid4       clientid;
        opaque          owner<NFS4_OPAQUE_LIMIT>;
};
```

This structure is used to identify the owner of open state. NFS4_OPAQUE_LIMIT is defined as 1024.

2.2.14. lock_owner4

```
struct lock_owner4 {
        clientid4       clientid;
        opaque          owner<NFS4_OPAQUE_LIMIT>;
};
```

This structure is used to identify the owner of file locking state. NFS4_OPAQUE_LIMIT is defined as 1024.

2.2.15. open_to_lock_owner4

```
struct open_to_lock_owner4 {
        seqid4          open_seqid;
        stateid4        open_stateid;
        seqid4          lock_seqid;
        lock_owner4     lock_owner;
};
```

This structure is used for the first LOCK operation done for an open_owner4. It provides both the open_stateid and lock_owner such that the transition is made from a valid open_stateid sequence to that of the new lock_stateid sequence. Using this mechanism avoids the confirmation of the lock_owner/lock_seqid pair since it is tied to established state in the form of the open_stateid/open_seqid.

2.2.16. stateid4

```
struct stateid4 {
        uint32_t        seqid;
        opaque          other[12];
};
```

This structure is used for the various state sharing mechanisms between the client and server. For the client, this data structure is read-only. The server is required to increment the seqid field monotonically at each transition of the stateid. This is important since the client will inspect the seqid in OPEN stateids to determine the order of OPEN processing done by the server.

3. RPC and Security Flavor

The NFSv4 protocol is a Remote Procedure Call (RPC) application that uses RPC version 2 and the corresponding eXternal Data Representation (XDR) as defined in [4] and [15]. The RPCSEC_GSS security flavor as defined in [5] MUST be implemented as the mechanism to deliver stronger security for the NFSv4 protocol. However, deployment of RPCSEC_GSS is optional.

3.1. Ports and Transports

Historically, NFSv2 and NFSv3 servers have resided on port 2049. The registered port 2049 [17] for the NFS protocol SHOULD be the default configuration. Using the registered port for NFS services means the NFS client will not need to use the RPC binding protocols as described in [18]; this will allow NFS to transit firewalls.

Where an NFSv4 implementation supports operation over the IP network protocol, the supported transports between NFS and IP MUST be among the IETF-approved congestion control transport protocols, which include TCP and SCTP. To enhance the possibilities for interoperability, an NFSv4 implementation MUST support operation over the TCP transport protocol, at least until such time as a standards track RFC revises this requirement to use a different IETF-approved congestion control transport protocol.

If TCP is used as the transport, the client and server SHOULD use persistent connections. This will prevent the weakening of TCP's congestion control via short lived connections and will improve performance for the WAN environment by eliminating the need for SYN handshakes.

To date, all NFSv4 implementations are TCP based, i.e., there are none for SCTP nor UDP. UDP by itself is not sufficient as a transport for NFSv4, neither is UDP in combination with some other mechanism (e.g., DCCP [19], NORM [20]).

As noted in Section 17, the authentication model for NFSv4 has moved from machine-based to principal-based. However, this modification of the authentication model does not imply a technical requirement to move the TCP connection management model from whole machine-based to one based on a per user model. In particular, NFS over TCP client implementations have traditionally multiplexed traffic for multiple users over a common TCP connection between an NFS client and server. This has been true, regardless whether the NFS client is using AUTH_SYS, AUTH_DH, RPCSEC_GSS or any other flavor. Similarly, NFS over TCP server implementations have assumed such a model and thus scale the implementation of TCP connection management in proportion to the number of expected client machines. It is intended that NFSv4 will not modify this connection management model. NFSv4 clients that violate this assumption can expect scaling issues on the server and hence reduced service.

Note that for various timers, the client and server should avoid inadvertent synchronization of those timers. For further discussion of the general issue refer to [21].

3.1.1. Client Retransmission Behavior

When processing a request received over a reliable transport such as TCP, the NFSv4 server MUST NOT silently drop the request, except if the transport connection has been broken. Given such a contract between NFSv4 clients and servers, clients MUST NOT retry a request unless one or both of the following are true:

- The transport connection has been broken

- The procedure being retried is the NULL procedure

Since reliable transports, such as TCP, do not always synchronously inform a peer when the other peer has broken the connection (for example, when an NFS server reboots), the NFSv4 client may want to actively "probe" the connection to see if has been broken. Use of the NULL procedure is one recommended way to do so. So, when a client experiences a remote procedure call timeout (of some arbitrary implementation specific amount), rather than retrying the remote procedure call, it could instead issue a NULL procedure call to the server. If the server has died, the transport connection break will eventually be indicated to the NFSv4 client. The client can then reconnect, and then retry the original request. If the NULL procedure call gets a response, the connection has not broken. The client can decide to wait longer for the original request's response, or it can break the transport connection and reconnect before re-sending the original request.

For callbacks from the server to the client, the same rules apply, but the server doing the callback becomes the client, and the client receiving the callback becomes the server.

3.2. Security Flavors

Traditional RPC implementations have included AUTH_NONE, AUTH_SYS, AUTH_DH, and AUTH_KRB4 as security flavors. With [5] an additional security flavor of RPCSEC_GSS has been introduced which uses the functionality of GSS-API [6]. This allows for the use of various security mechanisms by the RPC layer without the additional implementation overhead of adding RPC security flavors. For NFSv4, the RPCSEC_GSS security flavor MUST be used to enable the mandatory security mechanism. Other flavors, such as, AUTH_NONE, AUTH_SYS, and AUTH_DH MAY be implemented as well.

3.2.1. Security mechanisms for NFSv4

The use of RPCSEC_GSS requires selection of: mechanism, quality of protection, and service (authentication, integrity, privacy). The remainder of this document will refer to these three parameters of the RPCSEC_GSS security as the security triple.

3.2.1.1. Kerberos V5 as a security triple

The Kerberos V5 GSS-API mechanism as described in [16] MUST be implemented and provide the following security triples.

column descriptions:

1 == number of pseudo flavor
2 == name of pseudo flavor
3 == mechanism's OID
4 == mechanism's algorithm(s)
5 == RPCSEC_GSS service

1	2	3	4	5
390003	krb5	1.2.840.113554.1.2.2	DES MAC MD5	rpc_gss_svc_none
390004	krb5i	1.2.840.113554.1.2.2	DES MAC MD5 for integrity, and 56 bit DES for privacy.	rpc_gss_svc_integrity
390005	krb5p	1.2.840.113554.1.2.2	DES MAC MD5 for integrity, and 56 bit DES for privacy.	rpc_gss_svc_privacy

Note that the pseudo flavor is presented here as a mapping aid to the implementor. Because this NFS protocol includes a method to negotiate security and it understands the GSS-API mechanism, the pseudo flavor is not needed. The pseudo flavor is needed for NFSv3 since the security negotiation is done via the MOUNT protocol.

For a discussion of NFS' use of RPCSEC_GSS and Kerberos V5, please see [22].

3.3. Security Negotiation

With the NFSv4 server potentially offering multiple security mechanisms, the client needs a method to determine or negotiate which mechanism is to be used for its communication with the server. The NFS server may have multiple points within its filesystem name space that are available for use by NFS clients. In turn the NFS server may be configured such that each of these entry points may have different or multiple security mechanisms in use.

The security negotiation between client and server SHOULD be done with a secure channel to eliminate the possibility of a third party intercepting the negotiation sequence and forcing the client and server to choose a lower level of security than required or desired. See Section 17 for further discussion.

3.3.1. SECINFO

The new SECINFO operation will allow the client to determine, on a per filehandle basis, what security triple is to be used for server access. In general, the client will not have to use the SECINFO operation except during initial communication with the server or when

the client crosses policy boundaries at the server. It is possible that the server's policies change during the client's interaction therefore forcing the client to negotiate a new security triple.

3.3.2. Security Error

Based on the assumption that each NFSv4 client and server MUST support a minimum set of security (i.e., Kerberos-V5 under RPCSEC_GSS), the NFS client will start its communication with the server with one of the minimal security triples. During communication with the server, the client may receive an NFS error of NFS4ERR_WRONGSEC. This error allows the server to notify the client that the security triple currently being used is not appropriate for access to the server's filesystem resources. The client is then responsible for determining what security triples are available at the server and choose one which is appropriate for the client. See Section 15.33 for further discussion of how the client will respond to the NFS4ERR_WRONGSEC error and use SECINFO.

3.3.3. Callback RPC Authentication

Except as noted elsewhere in this section, the callback RPC (described later) MUST mutually authenticate the NFS server to the principal that acquired the client ID (also described later), using the security flavor the original SETCLIENTID operation used.

For AUTH_NONE, there are no principals, so this is a non-issue.

AUTH_SYS has no notions of mutual authentication or a server principal, so the callback from the server simply uses the AUTH_SYS credential that the user used when he set up the delegation.

For AUTH_DH, one commonly used convention is that the server uses the credential corresponding to this AUTH_DH principal:

```
unix.host@domain
```

where host and domain are variables corresponding to the name of server host and directory services domain in which it lives such as a Network Information System domain or a DNS domain.

Regardless of what security mechanism under RPCSEC_GSS is being used, the NFS server MUST identify itself in GSS-API via a GSS_C_NT_HOSTBASED_SERVICE name type. GSS_C_NT_HOSTBASED_SERVICE names are of the form:

```
service@hostname
```

For NFS, the "service" element is

nfs

Implementations of security mechanisms will convert nfs@hostname to various different forms. For Kerberos V5, the following form is RECOMMENDED:

nfs/hostname

For Kerberos V5, nfs/hostname would be a server principal in the Kerberos Key Distribution Center database. This is the same principal the client acquired a GSS-API context for when it issued the SETCLIENTID operation, therefore, the realm name for the server principal must be the same for the callback as it was for the SETCLIENTID.

4. Filehandles

The filehandle in the NFS protocol is a per server unique identifier for a filesystem object. The contents of the filehandle are opaque to the client. Therefore, the server is responsible for translating the filehandle to an internal representation of the filesystem object.

4.1. Obtaining the First Filehandle

The operations of the NFS protocol are defined in terms of one or more filehandles. Therefore, the client needs a filehandle to initiate communication with the server. With the NFSv2 protocol [13] and the NFSv3 protocol [14], there exists an ancillary protocol to obtain this first filehandle. The MOUNT protocol, RPC program number 100005, provides the mechanism of translating a string based filesystem path name to a filehandle which can then be used by the NFS protocols.

The MOUNT protocol has deficiencies in the area of security and use via firewalls. This is one reason that the use of the public filehandle was introduced in [23] and [24]. With the use of the public filehandle in combination with the LOOKUP operation in the NFSv2 and NFSv3 protocols, it has been demonstrated that the MOUNT protocol is unnecessary for viable interaction between NFS client and server.

Therefore, the NFSv4 protocol will not use an ancillary protocol for translation from string based path names to a filehandle. Two special filehandles will be used as starting points for the NFS

client.

4.1.1. Root Filehandle

The first of the special filehandles is the ROOT filehandle. The ROOT filehandle is the "conceptual" root of the filesystem name space at the NFS server. The client uses or starts with the ROOT filehandle by employing the PUTROOTFH operation. The PUTROOTFH operation instructs the server to set the "current" filehandle to the ROOT of the server's file tree. Once this PUTROOTFH operation is used, the client can then traverse the entirety of the server's file tree with the LOOKUP operation. A complete discussion of the server name space is in Section 8.

4.1.2. Public Filehandle

The second special filehandle is the PUBLIC filehandle. Unlike the ROOT filehandle, the PUBLIC filehandle may be bound or represent an arbitrary filesystem object at the server. The server is responsible for this binding. It may be that the PUBLIC filehandle and the ROOT filehandle refer to the same filesystem object. However, it is up to the administrative software at the server and the policies of the server administrator to define the binding of the PUBLIC filehandle and server filesystem object. The client may not make any assumptions about this binding. The client uses the PUBLIC filehandle via the PUTPUBFH operation.

4.2. Filehandle Types

In the NFSv2 and NFSv3 protocols, there was one type of filehandle with a single set of semantics. This type of filehandle is termed "persistent" in NFS Version 4. The semantics of a persistent filehandle remain the same as before. A new type of filehandle introduced in NFS Version 4 is the "volatile" filehandle, which attempts to accommodate certain server environments.

The volatile filehandle type was introduced to address server functionality or implementation issues which make correct implementation of a persistent filehandle infeasible. Some server environments do not provide a filesystem level invariant that can be used to construct a persistent filehandle. The underlying server filesystem may not provide the invariant or the server's filesystem programming interfaces may not provide access to the needed invariant. Volatile filehandles may ease the implementation of server functionality such as hierarchical storage management or filesystem reorganization or migration. However, the volatile filehandle increases the implementation burden for the client.

Since the client will need to handle persistent and volatile filehandles differently, a file attribute is defined which may be used by the client to determine the filehandle types being returned by the server.

4.2.1. General Properties of a Filehandle

The filehandle contains all the information the server needs to distinguish an individual file. To the client, the filehandle is opaque. The client stores filehandles for use in a later request and can compare two filehandles from the same server for equality by doing a byte-by-byte comparison. However, the client MUST NOT otherwise interpret the contents of filehandles. If two filehandles from the same server are equal, they MUST refer to the same file. Servers SHOULD try to maintain a one-to-one correspondence between filehandles and files but this is not required. Clients MUST use filehandle comparisons only to improve performance, not for correct behavior. All clients need to be prepared for situations in which it cannot be determined whether two filehandles denote the same object and in such cases, avoid making invalid assumptions which might cause incorrect behavior. Further discussion of filehandle and attribute comparison in the context of data caching is presented in Section 10.3.4.

As an example, in the case that two different path names when traversed at the server terminate at the same filesystem object, the server SHOULD return the same filehandle for each path. This can occur if a hard link is used to create two file names which refer to the same underlying file object and associated data. For example, if paths /a/b/c and /a/d/c refer to the same file, the server SHOULD return the same filehandle for both path names traversals.

4.2.2. Persistent Filehandle

A persistent filehandle is defined as having a fixed value for the lifetime of the filesystem object to which it refers. Once the server creates the filehandle for a filesystem object, the server MUST accept the same filehandle for the object for the lifetime of the object. If the server restarts or reboots the NFS server must honor the same filehandle value as it did in the server's previous instantiation. Similarly, if the filesystem is migrated, the new NFS server must honor the same filehandle as the old NFS server.

The persistent filehandle will be become stale or invalid when the filesystem object is removed. When the server is presented with a persistent filehandle that refers to a deleted object, it MUST return an error of NFS4ERR_STALE. A filehandle may become stale when the filesystem containing the object is no longer available. The file

system may become unavailable if it exists on removable media and the media is no longer available at the server or the filesystem in whole has been destroyed or the filesystem has simply been removed from the server's name space (i.e., unmounted in a UNIX environment).

4.2.3. Volatile Filehandle

A volatile filehandle does not share the same longevity characteristics of a persistent filehandle. The server may determine that a volatile filehandle is no longer valid at many different points in time. If the server can definitively determine that a volatile filehandle refers to an object that has been removed, the server should return NFS4ERR_STALE to the client (as is the case for persistent filehandles). In all other cases where the server determines that a volatile filehandle can no longer be used, it should return an error of NFS4ERR_FHEXPIRED.

The mandatory attribute "fh_expire_type" is used by the client to determine what type of filehandle the server is providing for a particular filesystem. This attribute is a bitmask with the following values:

FH4_PERSISTENT: The value of FH4_PERSISTENT is used to indicate a persistent filehandle, which is valid until the object is removed from the filesystem. The server will not return NFS4ERR_FHEXPIRED for this filehandle. FH4_PERSISTENT is defined as a value in which none of the bits specified below are set.

FH4_VOLATILE_ANY: The filehandle may expire at any time, except as specifically excluded (i.e., FH4_NOEXPIRE_WITH_OPEN).

FH4_NOEXPIRE_WITH_OPEN: May only be set when FH4_VOLATILE_ANY is set. If this bit is set, then the meaning of FH4_VOLATILE_ANY is qualified to exclude any expiration of the filehandle when it is open.

FH4_VOL_MIGRATION: The filehandle will expire as a result of migration. If FH4_VOLATILE_ANY is set, FH4_VOL_MIGRATION is redundant.

FH4_VOL_RENAME: The filehandle will expire during rename. This includes a rename by the requesting client or a rename by any other client. If FH4_VOLATILE_ANY is set, FH4_VOL_RENAME is redundant.

Servers which provide volatile filehandles that may expire while open (i.e., if FH4_VOL_MIGRATION or FH4_VOL_RENAME is set or if FH4_VOLATILE_ANY is set and FH4_NOEXPIRE_WITH_OPEN not set), should

deny a RENAME or REMOVE that would affect an OPEN file of any of the components leading to the OPEN file. In addition, the server should deny all RENAME or REMOVE requests during the grace period upon server restart.

Note that the bits FH4_VOL_MIGRATION and FH4_VOL_RENAME allow the client to determine that expiration has occurred whenever a specific event occurs, without an explicit filehandle expiration error from the server. FH4_VOLATILE_ANY does not provide this form of information. In situations where the server will expire many, but not all filehandles upon migration (e.g., all but those that are open), FH4_VOLATILE_ANY (in this case with FH4_NOEXPIRE_WITH_OPEN) is a better choice since the client may not assume that all filehandles will expire when migration occurs, and it is likely that additional expirations will occur (as a result of file CLOSE) that are separated in time from the migration event itself.

4.2.4. One Method of Constructing a Volatile Filehandle

A volatile filehandle, while opaque to the client could contain:

```
[volatile bit = 1 | server boot time | slot | generation number]
```

- slot is an index in the server volatile filehandle table
- generation number is the generation number for the table entry/ slot

When the client presents a volatile filehandle, the server makes the following checks, which assume that the check for the volatile bit has passed. If the server boot time is less than the current server boot time, return NFS4ERR_FHEXPIRED. If slot is out of range, return NFS4ERR_BADHANDLE. If the generation number does not match, return NFS4ERR_FHEXPIRED.

When the server reboots, the table is gone (it is volatile).

If volatile bit is 0, then it is a persistent filehandle with a different structure following it.

4.3. Client Recovery from Filehandle Expiration

If possible, the client SHOULD recover from the receipt of an NFS4ERR_FHEXPIRED error. The client must take on additional responsibility so that it may prepare itself to recover from the expiration of a volatile filehandle. If the server returns persistent filehandles, the client does not need these additional steps.

For volatile filehandles, most commonly the client will need to store the component names leading up to and including the filesystem object in question. With these names, the client should be able to recover by finding a filehandle in the name space that is still available or by starting at the root of the server's filesystem name space.

If the expired filehandle refers to an object that has been removed from the filesystem, obviously the client will not be able to recover from the expired filehandle.

It is also possible that the expired filehandle refers to a file that has been renamed. If the file was renamed by another client, again it is possible that the original client will not be able to recover. However, in the case that the client itself is renaming the file and the file is open, it is possible that the client may be able to recover. The client can determine the new path name based on the processing of the rename request. The client can then regenerate the new filehandle based on the new path name. The client could also use the compound operation mechanism to construct a set of operations like:

```
RENAME A B
LOOKUP B
GETFH
```

Note that the COMPOUND procedure does not provide atomicity. This example only reduces the overhead of recovering from an expired filehandle.

5. File Attributes

To meet the requirements of extensibility and increased interoperability with non-UNIX platforms, attributes need to be handled in a flexible manner. The NFSv3 fattr3 structure contains a fixed list of attributes that not all clients and servers are able to support or care about. The fattr3 structure cannot be extended as new needs arise and it provides no way to indicate non-support. With the NFSv4.0 protocol, the client is able to query what attributes the server supports and construct requests with only those supported attributes (or a subset thereof).

To this end, attributes are divided into three groups: REQUIRED, RECOMMENDED, and named. Both REQUIRED and RECOMMENDED attributes are supported in the NFSv4.0 protocol by a specific and well-defined encoding and are identified by number. They are requested by setting a bit in the bit vector sent in the GETATTR request; the server response includes a bit vector to list what attributes were returned

in the response. New REQUIRED or RECOMMENDED attributes may be added to the NFSv4 protocol as part of a new minor version by publishing a Standards Track RFC which allocates a new attribute number value and defines the encoding for the attribute. See Section 11 for further discussion.

Named attributes are accessed by the new OPENATTR operation, which accesses a hidden directory of attributes associated with a file system object. OPENATTR takes a filehandle for the object and returns the filehandle for the attribute hierarchy. The filehandle for the named attributes is a directory object accessible by LOOKUP or READDIR and contains files whose names represent the named attributes and whose data bytes are the value of the attribute. For example:

```
+----------+-----------+---------------------------------+
| LOOKUP   | "foo"     | ; look up file                  |
| GETATTR  | attrbits  |                                 |
| OPENATTR |           | ; access foo's named attributes |
| LOOKUP   | "x11icon" | ; look up specific attribute    |
| READ     | 0,4096    | ; read stream of bytes          |
+----------+-----------+---------------------------------+
```

Named attributes are intended for data needed by applications rather than by an NFS client implementation. NFS implementors are strongly encouraged to define their new attributes as RECOMMENDED attributes by bringing them to the IETF Standards Track process.

The set of attributes that are classified as REQUIRED is deliberately small since servers need to do whatever it takes to support them. A server should support as many of the RECOMMENDED attributes as possible but, by their definition, the server is not required to support all of them. Attributes are deemed REQUIRED if the data is both needed by a large number of clients and is not otherwise reasonably computable by the client when support is not provided on the server.

Note that the hidden directory returned by OPENATTR is a convenience for protocol processing. The client should not make any assumptions about the server's implementation of named attributes and whether or not the underlying file system at the server has a named attribute directory. Therefore, operations such as SETATTR and GETATTR on the named attribute directory are undefined.

5.1. REQUIRED Attributes

These MUST be supported by every NFSv4.0 client and server in order to ensure a minimum level of interoperability. The server MUST store

and return these attributes, and the client MUST be able to function with an attribute set limited to these attributes. With just the REQUIRED attributes some client functionality may be impaired or limited in some ways. A client may ask for any of these attributes to be returned by setting a bit in the GETATTR request, and the server must return their value.

5.2. RECOMMENDED Attributes

These attributes are understood well enough to warrant support in the NFSv4.0 protocol. However, they may not be supported on all clients and servers. A client MAY ask for any of these attributes to be returned by setting a bit in the GETATTR request but must handle the case where the server does not return them. A client MAY ask for the set of attributes the server supports and SHOULD NOT request attributes the server does not support. A server should be tolerant of requests for unsupported attributes and simply not return them rather than considering the request an error. It is expected that servers will support all attributes they comfortably can and only fail to support attributes that are difficult to support in their operating environments. A server should provide attributes whenever they don't have to "tell lies" to the client. For example, a file modification time should be either an accurate time or should not be supported by the server. At times this will be difficult for clients, but a client is better positioned to decide whether and how to fabricate or construct an attribute or whether to do without the attribute.

5.3. Named Attributes

These attributes are not supported by direct encoding in the NFSv4 protocol but are accessed by string names rather than numbers and correspond to an uninterpreted stream of bytes that are stored with the file system object. The name space for these attributes may be accessed by using the OPENATTR operation. The OPENATTR operation returns a filehandle for a virtual "named attribute directory", and further perusal and modification of the name space may be done using operations that work on more typical directories. In particular, READDIR may be used to get a list of such named attributes, and LOOKUP and OPEN may select a particular attribute. Creation of a new named attribute may be the result of an OPEN specifying file creation.

Once an OPEN is done, named attributes may be examined and changed by normal READ and WRITE operations using the filehandles and stateids returned by OPEN.

Named attributes and the named attribute directory may have their own

(non-named) attributes. Each of these objects must have all of the REQUIRED attributes and may have additional RECOMMENDED attributes. However, the set of attributes for named attributes and the named attribute directory need not be, and typically will not be, as large as that for other objects in that file system.

Named attributes might be the target of delegations. However, since granting of delegations is at the server's discretion, a server need not support delegations on named attributes.

It is RECOMMENDED that servers support arbitrary named attributes. A client should not depend on the ability to store any named attributes in the server's file system. If a server does support named attributes, a client that is also able to handle them should be able to copy a file's data and metadata with complete transparency from one location to another; this would imply that names allowed for regular directory entries are valid for named attribute names as well.

In NFSv4.0, the structure of named attribute directories is restricted in a number of ways, in order to prevent the development of non-interoperable implementations in which some servers support a fully general hierarchical directory structure for named attributes while others support a limited but adequate structure for named attributes. In such an environment, clients or applications might come to depend on non-portable extensions. The restrictions are:

- CREATE is not allowed in a named attribute directory. Thus, such objects as symbolic links and special files are not allowed to be named attributes. Further, directories may not be created in a named attribute directory, so no hierarchical structure of named attributes for a single object is allowed.

- If OPENATTR is done on a named attribute directory or on a named attribute, the server MUST return an error.

- Doing a RENAME of a named attribute to a different named attribute directory or to an ordinary (i.e., non-named-attribute) directory is not allowed.

- Creating hard links between named attribute directories or between named attribute directories and ordinary directories is not allowed.

Names of attributes will not be controlled by this document or other IETF Standards Track documents. See Section 18 for further discussion.

5.4. Classification of Attributes

Each of the REQUIRED and RECOMMENDED attributes can be classified in one of three categories: per server (i.e., the value of the attribute will be the same for all file objects that share the same server), per file system (i.e., the value of the attribute will be the same for some or all file objects that share the same fsid attribute (Section 5.8.1.9) and server owner), or per file system object. Note that it is possible that some per file system attributes may vary within the file system. Note that it is possible that some per file system attributes may vary within the file system, depending on the value of the "homogeneous" (Section 5.8.2.16) attribute. Note that the attributes time_access_set and time_modify_set are not listed in this section because they are write-only attributes corresponding to time_access and time_modify, and are used in a special instance of SETATTR.

- The per-server attribute is:

  lease_time

- The per-file system attributes are:

  supported_attrs, fh_expire_type, link_support, symlink_support, unique_handles, aclsupport, cansettime, case_insensitive, case_preserving, chown_restricted, files_avail, files_free, files_total, fs_locations, homogeneous, maxfilesize, maxname, maxread, maxwrite, no_trunc, space_avail, space_free, space_total, time_delta,

- The per-file system object attributes are:

  type, change, size, named_attr, fsid, rdattr_error, filehandle, acl, archive, fileid, hidden, maxlink, mimetype, mode, numlinks, owner, owner_group, rawdev, space_used, system, time_access, time_backup, time_create, time_metadata, time_modify, mounted_on_fileid

For quota_avail_hard, quota_avail_soft, and quota_used, see their definitions below for the appropriate classification.

5.5. Set-Only and Get-Only Attributes

Some REQUIRED and RECOMMENDED attributes are set-only; i.e., they can be set via SETATTR but not retrieved via GETATTR. Similarly, some REQUIRED and RECOMMENDED attributes are get-only; i.e., they can be retrieved via GETATTR but not set via SETATTR. If a client attempts to set a get-only attribute or get a set-only attribute, the server

MUST return NFS4ERR_INVAL.

5.6. REQUIRED Attributes - List and Definition References

The list of REQUIRED attributes appears in Table 2. The meaning of the columns of the table are:

- Name: The name of attribute
- Id: The number assigned to the attribute. In the event of conflicts between the assigned number and [2], the latter is likely authoritative, but should be resolved with Errata to this document and/or [2]. See [25] for the Errata process.
- Data Type: The XDR data type of the attribute.
- Acc: Access allowed to the attribute. R means read-only (GETATTR may retrieve, SETATTR may not set). W means write-only (SETATTR may set, GETATTR may not retrieve). R W means read/write (GETATTR may retrieve, SETATTR may set).
- Defined in: The section of this specification that describes the attribute.

Name	Id	Data Type	Acc	Defined in:
supported_attrs	0	bitmap4	R	Section 5.8.1.1
type	1	nfs_ftype4	R	Section 5.8.1.2
fh_expire_type	2	uint32_t	R	Section 5.8.1.3
change	3	uint64_t	R	Section 5.8.1.4
size	4	uint64_t	R W	Section 5.8.1.5
link_support	5	bool	R	Section 5.8.1.6
symlink_support	6	bool	R	Section 5.8.1.7
named_attr	7	bool	R	Section 5.8.1.8
fsid	8	fsid4	R	Section 5.8.1.9
unique_handles	9	bool	R	Section 5.8.1.10
lease_time	10	nfs_lease4	R	Section 5.8.1.11
rdattr_error	11	enum	R	Section 5.8.1.12
filehandle	19	nfs_fh4	R	Section 5.8.1.13

Table 2

5.7. RECOMMENDED Attributes - List and Definition References

The RECOMMENDED attributes are defined in Table 3. The meanings of the column headers are the same as Table 2; see Section 5.6 for the meanings.

Name	Id	Data Type	Acc	Defined in:
acl	12	nfsace4<>	R W	Section 6.2.1
aclsupport	13	uint32_t	R	Section 6.2.1.2
archive	14	bool	R W	Section 5.8.2.1
cansettime	15	bool	R	Section 5.8.2.2
case_insensitive	16	bool	R	Section 5.8.2.3
case_preserving	17	bool	R	Section 5.8.2.4
chown_restricted	18	bool	R	Section 5.8.2.5
fileid	20	uint64_t	R	Section 5.8.2.6
files_avail	21	uint64_t	R	Section 5.8.2.7
files_free	22	uint64_t	R	Section 5.8.2.8
files_total	23	uint64_t	R	Section 5.8.2.9
fs_locations	24	fs_locations	R	Section 5.8.2.10
hidden	25	bool	R W	Section 5.8.2.11
homogeneous	26	bool	R	Section 5.8.2.12
maxfilesize	27	uint64_t	R	Section 5.8.2.13
maxlink	28	uint32_t	R	Section 5.8.2.14
maxname	29	uint32_t	R	Section 5.8.2.15
maxread	30	uint64_t	R	Section 5.8.2.16
maxwrite	31	uint64_t	R	Section 5.8.2.17
mimetype	32	utf8<>	R W	Section 5.8.2.18
mode	33	mode4	R W	Section 6.2.2
mounted_on_fileid	55	uint64_t	R	Section 5.8.2.19
no_trunc	34	bool	R	Section 5.8.2.20
numlinks	35	uint32_t	R	Section 5.8.2.21
owner	36	utf8<>	R W	Section 5.8.2.22
owner_group	37	utf8<>	R W	Section 5.8.2.23
quota_avail_hard	38	uint64_t	R	Section 5.8.2.24
quota_avail_soft	39	uint64_t	R	Section 5.8.2.25
quota_used	40	uint64_t	R	Section 5.8.2.26
rawdev	41	specdata4	R	Section 5.8.2.27
space_avail	42	uint64_t	R	Section 5.8.2.28
space_free	43	uint64_t	R	Section 5.8.2.29
space_total	44	uint64_t	R	Section 5.8.2.30
space_used	45	uint64_t	R	Section 5.8.2.31
system	46	bool	R W	Section 5.8.2.32
time_access	47	nfstime4	R	Section 5.8.2.33
time_access_set	48	settime4	W	Section 5.8.2.34
time_backup	49	nfstime4	R W	Section 5.8.2.35
time_create	50	nfstime4	R W	Section 5.8.2.36

time_delta	51	nfstime4	R	Section 5.8.2.37
time_metadata	52	nfstime4	R	Section 5.8.2.38
time_modify	53	nfstime4	R	Section 5.8.2.39
time_modify_set	54	settime4	W	Section 5.8.2.40

Table 3

5.8. Attribute Definitions

5.8.1. Definitions of REQUIRED Attributes

5.8.1.1. Attribute 0: supported_attrs

The bit vector that would retrieve all REQUIRED and RECOMMENDED attributes that are supported for this object. The scope of this attribute applies to all objects with a matching fsid.

5.8.1.2. Attribute 1: type

Designates the type of an object in terms of one of a number of special constants:

- NF4REG designates a regular file.
- NF4DIR designates a directory.
- NF4BLK designates a block device special file.
- NF4CHR designates a character device special file.
- NF4LNK designates a symbolic link.
- NF4SOCK designates a named socket special file.
- NF4FIFO designates a fifo special file.
- NF4ATTRDIR designates a named attribute directory.
- NF4NAMEDATTR designates a named attribute.

Within the explanatory text and operation descriptions, the following phrases will be used with the meanings given below:

- The phrase "is a directory" means that the object's type attribute is NF4DIR or NF4ATTRDIR.

- The phrase "is a special file" means that the object's type attribute is NF4BLK, NF4CHR, NF4SOCK, or NF4FIFO.

- The phrase "is an regular file" means that the object's type attribute is NF4REG or NF4NAMEDATTR.

5.8.1.3. Attribute 2: fh_expire_type

Server uses this to specify filehandle expiration behavior to the client. See Section 4 for additional description.

5.8.1.4. Attribute 3: change

A value created by the server that the client can use to determine if file data, directory contents, or attributes of the object have been modified. The server may return the object's time_metadata attribute for this attribute's value but only if the file system object cannot be updated more frequently than the resolution of time_metadata.

5.8.1.5. Attribute 4: size

The size of the object in bytes.

5.8.1.6. Attribute 5: link_support

TRUE, if the object's file system supports hard links.

5.8.1.7. Attribute 6: symlink_support

TRUE, if the object's file system supports symbolic links.

5.8.1.8. Attribute 7: named_attr

TRUE, if this object has named attributes. In other words, object has a non-empty named attribute directory.

5.8.1.9. Attribute 8: fsid

Unique file system identifier for the file system holding this object. The fsid attribute has major and minor components, each of which are of data type uint64_t.

5.8.1.10. Attribute 9: unique_handles

TRUE, if two distinct filehandles are guaranteed to refer to two different file system objects.

5.8.1.11. Attribute 10: lease_time

Duration of the lease at server in seconds.

5.8.1.12. Attribute 11: rdattr_error

Error returned from an attempt to retrieve attributes during a READDIR operation.

5.8.1.13. Attribute 19: filehandle

The filehandle of this object (primarily for READDIR requests).

5.8.2. Definitions of Uncategorized RECOMMENDED Attributes

The definitions of most of the RECOMMENDED attributes follow. Collections that share a common category are defined in other sections.

5.8.2.1. Attribute 14: archive

TRUE, if this file has been archived since the time of last modification (deprecated in favor of time_backup).

5.8.2.2. Attribute 15: cansettime

TRUE, if the server is able to change the times for a file system object as specified in a SETATTR operation.

5.8.2.3. Attribute 16: case_insensitive

TRUE, if file name comparisons on this file system are case insensitive.

5.8.2.4. Attribute 17: case_preserving

TRUE, if file name case on this file system is preserved.

5.8.2.5. Attribute 18: chown_restricted

If TRUE, the server will reject any request to change either the owner or the group associated with a file if the caller is not a privileged user (for example, "root" in UNIX operating environments or in Windows 2000, the "Take Ownership" privilege).

5.8.2.6. Attribute 20: fileid

A number uniquely identifying the file within the file system.

5.8.2.7. Attribute 21: files_avail

File slots available to this user on the file system containing this object -- this should be the smallest relevant limit.

5.8.2.8. Attribute 22: files_free

Free file slots on the file system containing this object - this should be the smallest relevant limit.

5.8.2.9. Attribute 23: files_total

Total file slots on the file system containing this object.

5.8.2.10. Attribute 24: fs_locations

Locations where this file system may be found. If the server returns NFS4ERR_MOVED as an error, this attribute MUST be supported.

The server can specify a root path by setting an array of zero path components. Other than this special case, the server MUST not present empty path components to the client.

5.8.2.11. Attribute 25: hidden

TRUE, if the file is considered hidden with respect to the Windows API.

5.8.2.12. Attribute 26: homogeneous

TRUE, if this object's file system is homogeneous, i.e., all objects in the file system (all objects on the server with the same fsid) have common values for all per-file-system attributes.

5.8.2.13. Attribute 27: maxfilesize

Maximum supported file size for the file system of this object.

5.8.2.14. Attribute 28: maxlink

Maximum number of links for this object.

5.8.2.15. Attribute 29: maxname

Maximum file name size supported for this object.

5.8.2.16. Attribute 30: maxread

Maximum amount of data the READ operation will return for this object.

5.8.2.17. Attribute 31: maxwrite

Maximum amount of data the WRITE operation will accept for this object. This attribute SHOULD be supported if the file is writable. Lack of this attribute can lead to the client either wasting bandwidth or not receiving the best performance.

5.8.2.18. Attribute 32: mimetype

MIME body type/subtype of this object.

5.8.2.19. Attribute 55: mounted_on_fileid

Like fileid, but if the target filehandle is the root of a file system, this attribute represents the fileid of the underlying directory.

UNIX-based operating environments connect a file system into the namespace by connecting (mounting) the file system onto the existing file object (the mount point, usually a directory) of an existing file system. When the mount point's parent directory is read via an API like readdir(), the return results are directory entries, each with a component name and a fileid. The fileid of the mount point's directory entry will be different from the fileid that the stat() system call returns. The stat() system call is returning the fileid of the root of the mounted file system, whereas readdir() is returning the fileid that stat() would have returned before any file systems were mounted on the mount point.

Unlike NFSv3, NFSv4.0 allows a client's LOOKUP request to cross other file systems. The client detects the file system crossing whenever the filehandle argument of LOOKUP has an fsid attribute different from that of the filehandle returned by LOOKUP. A UNIX-based client will consider this a "mount point crossing". UNIX has a legacy scheme for allowing a process to determine its current working directory. This relies on readdir() of a mount point's parent and stat() of the mount point returning fileids as previously described. The mounted_on_fileid attribute corresponds to the fileid that readdir() would have returned as described previously.

While the NFSv4.0 client could simply fabricate a fileid corresponding to what mounted_on_fileid provides (and if the server does not support mounted_on_fileid, the client has no choice), there is a risk that the client will generate a fileid that conflicts with one that is already assigned to another object in the file system. Instead, if the server can provide the mounted_on_fileid, the potential for client operational problems in this area is eliminated.

If the server detects that there is no mounted point at the target file object, then the value for mounted_on_fileid that it returns is the same as that of the fileid attribute.

The mounted_on_fileid attribute is RECOMMENDED, so the server SHOULD provide it if possible, and for a UNIX-based server, this is straightforward. Usually, mounted_on_fileid will be requested during a READDIR operation, in which case it is trivial (at least for UNIX-based servers) to return mounted_on_fileid since it is equal to the fileid of a directory entry returned by readdir(). If mounted_on_fileid is requested in a GETATTR operation, the server should obey an invariant that has it returning a value that is equal to the file object's entry in the object's parent directory, i.e., what readdir() would have returned. Some operating environments allow a series of two or more file systems to be mounted onto a single mount point. In this case, for the server to obey the aforementioned invariant, it will need to find the base mount point, and not the intermediate mount points.

5.8.2.20. Attribute 34: no_trunc

If this attribute is TRUE, then if the client uses a file name longer than name_max, an error will be returned instead of the name being truncated.

5.8.2.21. Attribute 35: numlinks

Number of hard links to this object.

5.8.2.22. Attribute 36: owner

The string name of the owner of this object.

5.8.2.23. Attribute 37: owner_group

The string name of the group ownership of this object.

5.8.2.24. Attribute 38: quota_avail_hard

The value in bytes that represents the amount of additional disk space beyond the current allocation that can be allocated to this file or directory before further allocations will be refused. It is understood that this space may be consumed by allocations to other files or directories.

5.8.2.25. Attribute 39: quota_avail_soft

The value in bytes that represents the amount of additional disk space that can be allocated to this file or directory before the user may reasonably be warned. It is understood that this space may be consumed by allocations to other files or directories though there is a rule as to which other files or directories.

5.8.2.26. Attribute 40: quota_used

The value in bytes that represents the amount of disc space used by this file or directory and possibly a number of other similar files or directories, where the set of "similar" meets at least the criterion that allocating space to any file or directory in the set will reduce the "quota_avail_hard" of every other file or directory in the set.

Note that there may be a number of distinct but overlapping sets of files or directories for which a quota_used value is maintained, e.g., "all files with a given owner", "all files with a given group owner", etc. The server is at liberty to choose any of those sets when providing the content of the quota_used attribute, but should do so in a repeatable way. The rule may be configured per file system or may be "choose the set with the smallest quota".

5.8.2.27. Attribute 41: rawdev

Raw device number of file of type NF4BLK or NF4CHR. The device number is split into major and minor numbers. If the file's type attribute is not NF4BLK or NF4CHR, the value returned SHOULD NOT be considered useful.

5.8.2.28. Attribute 42: space_avail

Disk space in bytes available to this user on the file system containing this object -- this should be the smallest relevant limit.

5.8.2.29. Attribute 43: space_free

Free disk space in bytes on the file system containing this object -- this should be the smallest relevant limit.

5.8.2.30. Attribute 44: space_total

Total disk space in bytes on the file system containing this object.

5.8.2.31. Attribute 45: space_used

Number of file system bytes allocated to this object.

5.8.2.32. Attribute 46: system

This attribute is TRUE if this file is a "system" file with respect to the Windows operating environment.

5.8.2.33. Attribute 47: time_access

The time_access attribute represents the time of last access to the object by a READ operation sent to the server. The notion of what is an "access" depends on the server's operating environment and/or the server's file system semantics. For example, for servers obeying Portable Operating System Interface (POSIX) semantics, time_access would be updated only by the READ and READDIR operations and not any of the operations that modify the content of the object [16], [17], [26], [27], [28]. Of course, setting the corresponding time_access_set attribute is another way to modify the time_access attribute.

Whenever the file object resides on a writable file system, the server should make its best efforts to record time_access into stable storage. However, to mitigate the performance effects of doing so, and most especially whenever the server is satisfying the read of the object's content from its cache, the server MAY cache access time updates and lazily write them to stable storage. It is also acceptable to give administrators of the server the option to disable time_access updates.

5.8.2.34. Attribute 48: time_access_set

Sets the time of last access to the object. SETATTR use only.

5.8.2.35. Attribute 49: time_backup

The time of last backup of the object.

5.8.2.36. Attribute 50: time_create

The time of creation of the object. This attribute does not have any relation to the traditional UNIX file attribute "ctime" or "change time".

5.8.2.37. Attribute 51: time_delta

Smallest useful server time granularity.

5.8.2.38. Attribute 52: time_metadata

The time of last metadata modification of the object.

5.8.2.39. Attribute 53: time_modify

The time of last modification to the object.

5.8.2.40. Attribute 54: time_modify_set

Sets the time of last modification to the object. SETATTR use only.

5.9. Interpreting owner and owner_group

The RECOMMENDED attributes "owner" and "owner_group" (and also users and groups within the "acl" attribute) are represented in terms of a UTF-8 string. To avoid a representation that is tied to a particular underlying implementation at the client or server, the use of the UTF-8 string has been chosen. Note that section 6.1 of RFC 2624 [29] provides additional rationale. It is expected that the client and server will have their own local representation of owner and owner_group that is used for local storage or presentation to the end user. Therefore, it is expected that when these attributes are transferred between the client and server, the local representation is translated to a syntax of the form "user@dns_domain". This will allow for a client and server that do not use the same local representation the ability to translate to a common syntax that can be interpreted by both.

Similarly, security principals may be represented in different ways by different security mechanisms. Servers normally translate these representations into a common format, generally that used by local storage, to serve as a means of identifying the users corresponding to these security principals. When these local identifiers are translated to the form of the owner attribute, associated with files created by such principals, they identify, in a common format, the users associated with each corresponding set of security principals.

The translation used to interpret owner and group strings is not specified as part of the protocol. This allows various solutions to be employed. For example, a local translation table may be consulted that maps a numeric identifier to the user@dns_domain syntax. A name service may also be used to accomplish the translation. A server may provide a more general service, not limited by any particular translation (which would only translate a limited set of possible strings) by storing the owner and owner_group attributes in local storage without any translation or it may augment a translation method by storing the entire string for attributes for which no translation is available while using the local representation for those cases in which a translation is available.

Servers that do not provide support for all possible values of the owner and owner_group attributes SHOULD return an error (NFS4ERR_BADOWNER) when a string is presented that has no translation, as the value to be set for a SETATTR of the owner, owner_group, or acl attributes. When a server does accept an owner or owner_group value as valid on a SETATTR (and similarly for the owner and group strings in an acl), it is promising to return that same string (for which see below) when a corresponding GETATTR is done. For some internationalization-related exceptions where this is not possible, see below. Configuration changes (including changes from the mapping of the string to the local representation) and ill-constructed name translations (those that contain aliasing) may make that promise impossible to honor. Servers should make appropriate efforts to avoid a situation in which these attributes have their values changed when no real change to ownership has occurred.

The "dns_domain" portion of the owner string is meant to be a DNS domain name. For example, user@example.org. Servers should accept as valid a set of users for at least one domain. A server may treat other domains as having no valid translations. A more general service is provided when a server is capable of accepting users for multiple domains, or for all domains, subject to security constraints.

As an implementation guide, both clients and servers may provide a means to configure the "dns_domain" portion of the owner string. For example, the DNS domain name might be "lab.example.org", but the user names are defined in "example.org". In the absence of such a configuration, or as a default, the current DNS domain name should be the value used for the "dns_domain".

As mentioned above, it is desirable that a server when accepting a string of the form user@domain or group@domain in an attribute, return this same string when that corresponding attribute is fetched. Internationalization issues (for a general discussion of which see

Section 12) make this impossible and the client needs to take note of the following situations:

- The string representing the domain may be converted to equivalent U-label, if presented using a form other a a U-label. See Section 12.6 for details.

- The user or group may be returned in a different form, due to normalization issues, although it will always be a canonically equivalent string. See Section 12.7.3 for details.

In the case where there is no translation available to the client or server, the attribute value will be constructed without the "@". Therefore, the absence of the "@" from the owner or owner_group attribute signifies that no translation was available at the sender and that the receiver of the attribute should not use that string as a basis for translation into its own internal format. Even though the attribute value cannot be translated, it may still be useful. In the case of a client, the attribute string may be used for local display of ownership.

To provide a greater degree of compatibility with NFSv3, which identified users and groups by 32-bit unsigned user identifiers and group identifiers, owner and group strings that consist of ASCII-encoded decimal numeric values with no leading zeros can be given a special interpretation by clients and servers that choose to provide such support. The receiver may treat such a user or group string as representing the same user as would be represented by an NFSv3 uid or gid having the corresponding numeric value.

A server SHOULD reject such a numeric value if the security mechanism is kerberized. I.e., in such a scenario, the client will already need to form "user@domain" strings. For any other security mechanism, the server SHOULD accept such numeric values. As an implementation note, the server could make such an acceptance be configurable. If the server does not support numeric values or if it is configured off, then it MUST return an NFS4ERR_BADOWNER error. If the security mechanism is kerberized and the client attempts to use the special form, then the server SHOULD return an NFS4ERR_BADOWNER error when there is a valid translation for the user or owner designated in this way. In that case, the client must use the appropriate user@domain string and not the special form for compatibility.

The client MUST always accept numeric values if the security mechanism is not RPCSEC_GSS. A client can determine if a server supports numeric identifiers by first attempting to provide a numeric identifier. If this attempt rejected with an NFS4ERR_BADOWNER error,

the the client should only use named identifiers of the form "user@dns_domain".

The owner string "nobody" may be used to designate an anonymous user, which will be associated with a file created by a security principal that cannot be mapped through normal means to the owner attribute.

5.10. Character Case Attributes

With respect to the case_insensitive and case_preserving attributes, each UCS-4 character (which UTF-8 encodes) has a "long descriptive name" RFC1345 [30] which may or may not include the word "CAPITAL" or "SMALL". The presence of SMALL or CAPITAL allows an NFS server to implement unambiguous and efficient table driven mappings for case insensitive comparisons, and non-case-preserving storage, although there are variations that occur additional characters with a name including "SMALL" or "CAPITAL" are added in a subsequent version of Unicode.

For general character handling and internationalization issues, see Section 12. For details regarding case mapping, see the section Case-based Mapping Used for Component4 Strings.

6. Access Control Attributes

Access Control Lists (ACLs) are file attributes that specify fine grained access control. This chapter covers the "acl", "aclsupport", "mode", file attributes, and their interactions. Note that file attributes may apply to any file system object.

6.1. Goals

ACLs and modes represent two well established models for specifying permissions. This chapter specifies requirements that attempt to meet the following goals:

- If a server supports the mode attribute, it should provide reasonable semantics to clients that only set and retrieve the mode attribute.

- If a server supports ACL attributes, it should provide reasonable semantics to clients that only set and retrieve those attributes.

- On servers that support the mode attribute, if ACL attributes have never been set on an object, via inheritance or explicitly, the behavior should be traditional UNIX-like behavior.

- On servers that support the mode attribute, if the ACL attributes have been previously set on an object, either explicitly or via inheritance:
  - Setting only the mode attribute should effectively control the traditional UNIX-like permissions of read, write, and execute on owner, owner_group, and other.
  - Setting only the mode attribute should provide reasonable security. For example, setting a mode of 000 should be enough to ensure that future opens for read or write by any principal fail, regardless of a previously existing or inherited ACL.
- When a mode attribute is set on an object, the ACL attributes may need to be modified so as to not conflict with the new mode. In such cases, it is desirable that the ACL keep as much information as possible. This includes information about inheritance, AUDIT and ALARM ACEs, and permissions granted and denied that do not conflict with the new mode.

6.2. File Attributes Discussion

6.2.1. Attribute 12: acl

The NFSv4.0 ACL attribute contains an array of access control entries (ACEs) that are associated with the file system object. Although the client can read and write the acl attribute, the server is responsible for using the ACL to perform access control. The client can use the OPEN or ACCESS operations to check access without modifying or reading data or metadata.

The NFS ACE structure is defined as follows:

```
typedef uint32_t        acetype4;


typedef uint32_t aceflag4;


typedef uint32_t        acemask4;


struct nfsace4 {
        acetype4                type;
        aceflag4                flag;
        acemask4                access_mask;
        utf8val_REQUIRED4       who;
};
```

To determine if a request succeeds, the server processes each nfsace4 entry in order. Only ACEs which have a "who" that matches the requester are considered. Each ACE is processed until all of the bits of the requester's access have been ALLOWED. Once a bit (see below) has been ALLOWED by an ACCESS_ALLOWED_ACE, it is no longer considered in the processing of later ACEs. If an ACCESS_DENIED_ACE is encountered where the requester's access still has unALLOWED bits in common with the "access_mask" of the ACE, the request is denied. When the ACL is fully processed, if there are bits in the requester's mask that have not been ALLOWED or DENIED, access is denied.

Unlike the ALLOW and DENY ACE types, the ALARM and AUDIT ACE types do not affect a requester's access, and instead are for triggering events as a result of a requester's access attempt. Therefore, AUDIT and ALARM ACEs are processed only after processing ALLOW and DENY ACEs.

The NFSv4.0 ACL model is quite rich. Some server platforms may provide access control functionality that goes beyond the UNIX-style mode attribute, but which is not as rich as the NFS ACL model. So that users can take advantage of this more limited functionality, the server may support the acl attributes by mapping between its ACL model and the NFSv4.0 ACL model. Servers must ensure that the ACL they actually store or enforce is at least as strict as the NFSv4 ACL that was set. It is tempting to accomplish this by rejecting any ACL that falls outside the small set that can be represented accurately. However, such an approach can render ACLs unusable without special client-side knowledge of the server's mapping, which defeats the purpose of having a common NFSv4 ACL protocol. Therefore servers should accept every ACL that they can without compromising security. To help accomplish this, servers may make a special exception, in the case of unsupported permission bits, to the rule that bits not ALLOWED or DENIED by an ACL must be denied. For example, a UNIX-style server might choose to silently allow read attribute permissions even though an ACL does not explicitly allow those permissions. (An ACL that explicitly denies permission to read attributes should still be rejected.)

The situation is complicated by the fact that a server may have multiple modules that enforce ACLs. For example, the enforcement for NFSv4.0 access may be different from, but not weaker than, the enforcement for local access, and both may be different from the enforcement for access through other protocols such as SMB. So it may be useful for a server to accept an ACL even if not all of its modules are able to support it.

The guiding principle with regard to NFSv4 access is that the server must not accept ACLs that appear to make access to the file more

restrictive than it really is.

6.2.1.1. ACE Type

The constants used for the type field (acetype4) are as follows:

```
const ACE4_ACCESS_ALLOWED_ACE_TYPE      = 0x00000000;
const ACE4_ACCESS_DENIED_ACE_TYPE       = 0x00000001;
const ACE4_SYSTEM_AUDIT_ACE_TYPE        = 0x00000002;
const ACE4_SYSTEM_ALARM_ACE_TYPE        = 0x00000003;
```

All four but types are permitted in the acl attribute.

Value	Abbreviation	Description
ACE4_ACCESS_ALLOWED_ACE_TYPE	ALLOW	Explicitly grants the access defined in acemask4 to the file or directory.
ACE4_ACCESS_DENIED_ACE_TYPE	DENY	Explicitly denies the access defined in acemask4 to the file or directory.
ACE4_SYSTEM_AUDIT_ACE_TYPE	AUDIT	LOG (in a system dependent way) any access attempt to a file or directory which uses any of the access methods specified in acemask4.
ACE4_SYSTEM_ALARM_ACE_TYPE	ALARM	Generate a system ALARM (system dependent) when any access attempt is made to a file or directory for the access methods specified in acemask4.

The "Abbreviation" column denotes how the types will be referred to throughout the rest of this chapter.

6.2.1.2. Attribute 13: aclsupport

A server need not support all of the above ACE types. This attribute indicates which ACE types are supported for the current file system. The bitmask constants used to represent the above definitions within the aclsupport attribute are as follows:

```
const ACL4_SUPPORT_ALLOW_ACL    = 0x00000001;
const ACL4_SUPPORT_DENY_ACL     = 0x00000002;
const ACL4_SUPPORT_AUDIT_ACL    = 0x00000004;
const ACL4_SUPPORT_ALARM_ACL    = 0x00000008;
```

Servers which support either the ALLOW or DENY ACE type SHOULD support both ALLOW and DENY ACE types.

Clients should not attempt to set an ACE unless the server claims support for that ACE type. If the server receives a request to set an ACE that it cannot store, it MUST reject the request with NFS4ERR_ATTRNOTSUPP. If the server receives a request to set an ACE that it can store but cannot enforce, the server SHOULD reject the request with NFS4ERR_ATTRNOTSUPP.

Support for any of the ACL attributes is optional (albeit, RECOMMENDED).

6.2.1.3. ACE Access Mask

The bitmask constants used for the access mask field are as follows:

```
const ACE4_READ_DATA            = 0x00000001;
const ACE4_LIST_DIRECTORY       = 0x00000001;
const ACE4_WRITE_DATA           = 0x00000002;
const ACE4_ADD_FILE             = 0x00000002;
const ACE4_APPEND_DATA          = 0x00000004;
const ACE4_ADD_SUBDIRECTORY     = 0x00000004;
const ACE4_READ_NAMED_ATTRS     = 0x00000008;
const ACE4_WRITE_NAMED_ATTRS    = 0x00000010;
const ACE4_EXECUTE              = 0x00000020;
const ACE4_DELETE_CHILD         = 0x00000040;
const ACE4_READ_ATTRIBUTES      = 0x00000080;
const ACE4_WRITE_ATTRIBUTES     = 0x00000100;

const ACE4_DELETE               = 0x00010000;
const ACE4_READ_ACL             = 0x00020000;
const ACE4_WRITE_ACL            = 0x00040000;
const ACE4_WRITE_OWNER          = 0x00080000;
const ACE4_SYNCHRONIZE          = 0x00100000;
```

Note that some masks have coincident values, for example, ACE4_READ_DATA and ACE4_LIST_DIRECTORY. The mask entries ACE4_LIST_DIRECTORY, ACE4_ADD_FILE, and ACE4_ADD_SUBDIRECTORY are intended to be used with directory objects, while ACE4_READ_DATA, ACE4_WRITE_DATA, and ACE4_APPEND_DATA are intended to be used with non-directory objects.

6.2.1.3.1. Discussion of Mask Attributes

ACE4_READ_DATA

Operation(s) affected:

READ

OPEN

Discussion:

Permission to read the data of the file.

Servers SHOULD allow a user the ability to read the data of the file when only the ACE4_EXECUTE access mask bit is allowed.

ACE4_LIST_DIRECTORY

Operation(s) affected:

READDIR

Discussion:

Permission to list the contents of a directory.

ACE4_WRITE_DATA

Operation(s) affected:

WRITE

OPEN

SETATTR of size

Discussion:

Permission to modify a file's data.

ACE4_ADD_FILE

Operation(s) affected:

CREATE

LINK

OPEN

RENAME

Discussion:

Permission to add a new file in a directory. The CREATE operation is affected when nfs_ftype4 is NF4LNK, NF4BLK, NF4CHR, NF4SOCK, or NF4FIFO. (NF4DIR is not listed because it is covered by ACE4_ADD_SUBDIRECTORY.) OPEN is affected when used to create a regular file. LINK and RENAME are always affected.

ACE4_APPEND_DATA

Operation(s) affected:

WRITE

OPEN

SETATTR of size

Discussion:

The ability to modify a file's data, but only starting at EOF. This allows for the notion of append-only files, by allowing ACE4_APPEND_DATA and denying ACE4_WRITE_DATA to the same user or group. If a file has an ACL such as the one described above and a WRITE request is made for somewhere other than EOF, the server SHOULD return NFS4ERR_ACCESS.

ACE4_ADD_SUBDIRECTORY

Operation(s) affected:

CREATE

RENAME

Discussion:

Permission to create a subdirectory in a directory. The CREATE operation is affected when nfs_ftype4 is NF4DIR. The RENAME operation is always affected.

ACE4_READ_NAMED_ATTRS

Operation(s) affected:

OPENATTR

Discussion:

Permission to read the named attributes of a file or to lookup the named attributes directory. OPENATTR is affected when it is not used to create a named attribute directory. This is when 1.) createdir is TRUE, but a named attribute directory already exists, or 2.) createdir is FALSE.

ACE4_WRITE_NAMED_ATTRS

Operation(s) affected:

OPENATTR

Discussion:

Permission to write the named attributes of a file or to create a named attribute directory. OPENATTR is affected when it is used to create a named attribute directory. This is when createdir is TRUE and no named attribute directory exists. The ability to check whether or not a named attribute directory exists depends on the ability to look it up, therefore, users also need the ACE4_READ_NAMED_ATTRS permission in order to create a named attribute directory.

ACE4_EXECUTE

Operation(s) affected:

READ

Discussion:

Permission to execute a file.

Servers SHOULD allow a user the ability to read the data of the file when only the ACE4_EXECUTE access mask bit is allowed. This is because there is no way to execute a file without reading the contents. Though a server may treat ACE4_EXECUTE and ACE4_READ_DATA bits identically when deciding to permit a READ operation, it SHOULD still allow the two bits to be set independently in ACLs, and MUST distinguish between them when replying to ACCESS operations. In particular, servers SHOULD NOT silently turn on one of the two bits when the other is set, as that would make it impossible for the client to correctly enforce the distinction between read and execute permissions.

As an example, following a SETATTR of the following ACL:

nfsuser:ACE4_EXECUTE:ALLOW

A subsequent GETATTR of ACL for that file SHOULD return:

nfsuser:ACE4_EXECUTE:ALLOW

Rather than:

nfsuser:ACE4_EXECUTE/ACE4_READ_DATA:ALLOW

ACE4_EXECUTE

Operation(s) affected:

LOOKUP

OPEN

REMOVE

RENAME

LINK

CREATE

Discussion:

Permission to traverse/search a directory.

ACE4_DELETE_CHILD

Operation(s) affected:

REMOVE

RENAME

Discussion:

Permission to delete a file or directory within a directory. See Section 6.2.1.3.2 for information on ACE4_DELETE and ACE4_DELETE_CHILD interact.

ACE4_READ_ATTRIBUTES

Operation(s) affected:

GETATTR of file system object attributes

VERIFY

NVERIFY

READDIR

Discussion:

The ability to read basic attributes (non-ACLs) of a file. On a UNIX system, basic attributes can be thought of as the stat level attributes. Allowing this access mask bit would mean the entity can execute "ls -l" and stat. If a READDIR operation requests attributes, this mask must be allowed for the READDIR to succeed.

ACE4_WRITE_ATTRIBUTES

Operation(s) affected:

SETATTR of time_access_set, time_backup,

time_create, time_modify_set, mimetype, hidden, system

Discussion:

Permission to change the times associated with a file or directory to an arbitrary value. Also permission to change the mimetype, hidden and system attributes. A user having ACE4_WRITE_DATA or ACE4_WRITE_ATTRIBUTES will be allowed to set the times associated with a file to the current server time.

ACE4_DELETE

Operation(s) affected:

REMOVE

Discussion:

Permission to delete the file or directory. See Section 6.2.1.3.2 for information on ACE4_DELETE and ACE4_DELETE_CHILD interact.

ACE4_READ_ACL

Operation(s) affected:

GETATTR of acl

NVERIFY

VERIFY

Discussion:

Permission to read the ACL.

ACE4_WRITE_ACL

Operation(s) affected:

SETATTR of acl and mode

Discussion:

Permission to write the acl and mode attributes.

ACE4_WRITE_OWNER

Operation(s) affected:

SETATTR of owner and owner_group

Discussion:

Permission to write the owner and owner_group attributes. On UNIX systems, this is the ability to execute chown() and chgrp().

ACE4_SYNCHRONIZE

Operation(s) affected:

NONE

Discussion:

Permission to use the file object as a synchronization primitive for interprocess communication. This permission is not enforced or interpreted by the NFSv4.0 server on behalf of the client.

Typically, the ACE4_SYNCHRONIZE permission is only meaningful on local file systems, i.e., file systems not accessed via NFSv4.0. The reason that the permission bit exists is that some operating environments, such as Windows, use ACE4_SYNCHRONIZE.

For example, if a client copies a file that has ACE4_SYNCHRONIZE set from a local file system to an NFSv4.0 server, and then later copies the file from the NFSv4.0 server to a local file system, it is likely that if ACE4_SYNCHRONIZE was set in the original file, the client will want it set in the second copy. The first copy will not have the permission set unless the NFSv4.0 server has the means to set the ACE4_SYNCHRONIZE bit. The second copy will not have the permission set unless the NFSv4.0 server has the means to retrieve the ACE4_SYNCHRONIZE bit.

Server implementations need not provide the granularity of control that is implied by this list of masks. For example, POSIX-based

systems might not distinguish ACE4_APPEND_DATA (the ability to append to a file) from ACE4_WRITE_DATA (the ability to modify existing contents); both masks would be tied to a single "write" permission. When such a server returns attributes to the client, it would show both ACE4_APPEND_DATA and ACE4_WRITE_DATA if and only if the write permission is enabled.

If a server receives a SETATTR request that it cannot accurately implement, it should err in the direction of more restricted access, except in the previously discussed cases of execute and read. For example, suppose a server cannot distinguish overwriting data from appending new data, as described in the previous paragraph. If a client submits an ALLOW ACE where ACE4_APPEND_DATA is set but ACE4_WRITE_DATA is not (or vice versa), the server should either turn off ACE4_APPEND_DATA or reject the request with NFS4ERR_ATTRNOTSUPP.

6.2.1.3.2. ACE4_DELETE vs. ACE4_DELETE_CHILD

Two access mask bits govern the ability to delete a directory entry: ACE4_DELETE on the object itself (the "target"), and ACE4_DELETE_CHILD on the containing directory (the "parent").

Many systems also take the "sticky bit" (MODE4_SVTX) on a directory to allow unlink only to a user that owns either the target or the parent; on some such systems the decision also depends on whether the target is writable.

Servers SHOULD allow unlink if either ACE4_DELETE is permitted on the target, or ACE4_DELETE_CHILD is permitted on the parent. (Note that this is true even if the parent or target explicitly denies one of these permissions.)

If the ACLs in question neither explicitly ALLOW nor DENY either of the above, and if MODE4_SVTX is not set on the parent, then the server SHOULD allow the removal if and only if ACE4_ADD_FILE is permitted. In the case where MODE4_SVTX is set, the server may also require the remover to own either the parent or the target, or may require the target to be writable.

This allows servers to support something close to traditional UNIX-like semantics, with ACE4_ADD_FILE taking the place of the write bit.

6.2.1.4. ACE flag

The bitmask constants used for the flag field are as follows:

```
const ACE4_FILE_INHERIT_ACE             = 0x00000001;
const ACE4_DIRECTORY_INHERIT_ACE        = 0x00000002;
const ACE4_NO_PROPAGATE_INHERIT_ACE     = 0x00000004;
const ACE4_INHERIT_ONLY_ACE             = 0x00000008;
const ACE4_SUCCESSFUL_ACCESS_ACE_FLAG   = 0x00000010;
const ACE4_FAILED_ACCESS_ACE_FLAG       = 0x00000020;
const ACE4_IDENTIFIER_GROUP             = 0x00000040;
```

A server need not support any of these flags. If the server supports flags that are similar to, but not exactly the same as, these flags, the implementation may define a mapping between the protocol-defined flags and the implementation-defined flags.

For example, suppose a client tries to set an ACE with ACE4_FILE_INHERIT_ACE set but not ACE4_DIRECTORY_INHERIT_ACE. If the server does not support any form of ACL inheritance, the server should reject the request with NFS4ERR_ATTRNOTSUPP. If the server supports a single "inherit ACE" flag that applies to both files and directories, the server may reject the request (i.e., requiring the client to set both the file and directory inheritance flags). The server may also accept the request and silently turn on the ACE4_DIRECTORY_INHERIT_ACE flag.

6.2.1.4.1. Discussion of Flag Bits

ACE4_FILE_INHERIT_ACE
: Any non-directory file in any sub-directory will get this ACE inherited.

ACE4_DIRECTORY_INHERIT_ACE
: Can be placed on a directory and indicates that this ACE should be added to each new directory created.
If this flag is set in an ACE in an ACL attribute to be set on a non-directory file system object, the operation attempting to set the ACL SHOULD fail with NFS4ERR_ATTRNOTSUPP.

ACE4_INHERIT_ONLY_ACE
: Can be placed on a directory but does not apply to the directory; ALLOW and DENY ACEs with this bit set do not affect access to the directory, and AUDIT and ALARM ACEs with this bit set do not trigger log or alarm events. Such ACEs only take effect once they are applied (with this bit cleared) to newly created files and directories as specified by the above two flags.
If this flag is present on an ACE, but neither ACE4_DIRECTORY_INHERIT_ACE nor ACE4_FILE_INHERIT_ACE is present, then an operation attempting to set such an attribute SHOULD fail with NFS4ERR_ATTRNOTSUPP.

ACE4_NO_PROPAGATE_INHERIT_ACE
Can be placed on a directory. This flag tells the server that inheritance of this ACE should stop at newly created child directories.

ACE4_SUCCESSFUL_ACCESS_ACE_FLAG

ACE4_FAILED_ACCESS_ACE_FLAG
The ACE4_SUCCESSFUL_ACCESS_ACE_FLAG (SUCCESS) and ACE4_FAILED_ACCESS_ACE_FLAG (FAILED) flag bits may be set only on ACE4_SYSTEM_AUDIT_ACE_TYPE (AUDIT) and ACE4_SYSTEM_ALARM_ACE_TYPE (ALARM) ACE types. If during the processing of the file's ACL, the server encounters an AUDIT or ALARM ACE that matches the principal attempting the OPEN, the server notes that fact, and the presence, if any, of the SUCCESS and FAILED flags encountered in the AUDIT or ALARM ACE. Once the server completes the ACL processing, it then notes if the operation succeeded or failed. If the operation succeeded, and if the SUCCESS flag was set for a matching AUDIT or ALARM ACE, then the appropriate AUDIT or ALARM event occurs. If the operation failed, and if the FAILED flag was set for the matching AUDIT or ALARM ACE, then the appropriate AUDIT or ALARM event occurs. Either or both of the SUCCESS or FAILED can be set, but if neither is set, the AUDIT or ALARM ACE is not useful.

The previously described processing applies to ACCESS operations even when they return NFS4_OK. For the purposes of AUDIT and ALARM, we consider an ACCESS operation to be a "failure" if it fails to return a bit that was requested and supported.

ACE4_IDENTIFIER_GROUP
Indicates that the "who" refers to a GROUP as defined under UNIX or a GROUP ACCOUNT as defined under Windows. Clients and servers MUST ignore the ACE4_IDENTIFIER_GROUP flag on ACEs with a who value equal to one of the special identifiers outlined in Section 6.2.1.5.

6.2.1.5. ACE Who

The "who" field of an ACE is an identifier that specifies the principal or principals to whom the ACE applies. It may refer to a user or a group, with the flag bit ACE4_IDENTIFIER_GROUP specifying which.

There are several special identifiers which need to be understood universally, rather than in the context of a particular DNS domain. Some of these identifiers cannot be understood when an NFS client accesses the server, but have meaning when a local process accesses

the file. The ability to display and modify these permissions is permitted over NFS, even if none of the access methods on the server understands the identifiers.

Who	Description
OWNER	The owner of the file
GROUP	The group associated with the file.
EVERYONE	The world, including the owner and owning group.
INTERACTIVE	Accessed from an interactive terminal.
NETWORK	Accessed via the network.
DIALUP	Accessed as a dialup user to the server.
BATCH	Accessed from a batch job.
ANONYMOUS	Accessed without any authentication.
AUTHENTICATED	Any authenticated user (opposite of ANONYMOUS)
SERVICE	Access from a system service.

Table 4

To avoid conflict, these special identifiers are distinguished by an appended "@" and should appear in the form "xxxx@" (with no domain name after the "@"). For example: ANONYMOUS@.

The ACE4_IDENTIFIER_GROUP flag MUST be ignored on entries with these special identifiers. When encoding entries with these special identifiers, the ACE4_IDENTIFIER_GROUP flag SHOULD be set to zero.

6.2.1.5.1. Discussion of EVERYONE@

It is important to note that "EVERYONE@" is not equivalent to the UNIX "other" entity. This is because, by definition, UNIX "other" does not include the owner or owning group of a file. "EVERYONE@" means literally everyone, including the owner or owning group.

6.2.2. Attribute 33: mode

The NFSv4.0 mode attribute is based on the UNIX mode bits. The following bits are defined:

```
const MODE4_SUID = 0x800;  /* set user id on execution */
const MODE4_SGID = 0x400;  /* set group id on execution */
const MODE4_SVTX = 0x200;  /* save text even after use */
const MODE4_RUSR = 0x100;  /* read permission: owner */
const MODE4_WUSR = 0x080;  /* write permission: owner */
const MODE4_XUSR = 0x040;  /* execute permission: owner */
const MODE4_RGRP = 0x020;  /* read permission: group */
const MODE4_WGRP = 0x010;  /* write permission: group */
const MODE4_XGRP = 0x008;  /* execute permission: group */
const MODE4_ROTH = 0x004;  /* read permission: other */
const MODE4_WOTH = 0x002;  /* write permission: other */
const MODE4_XOTH = 0x001;  /* execute permission: other */
```

Bits MODE4_RUSR, MODE4_WUSR, and MODE4_XUSR apply to the principal identified in the owner attribute. Bits MODE4_RGRP, MODE4_WGRP, and MODE4_XGRP apply to principals identified in the owner_group attribute but who are not identified in the owner attribute. Bits MODE4_ROTH, MODE4_WOTH, MODE4_XOTH apply to any principal that does not match that in the owner attribute, and does not have a group matching that of the owner_group attribute.

Bits within the mode other than those specified above are not defined by this protocol. A server MUST NOT return bits other than those defined above in a GETATTR or READDIR operation, and it MUST return NFS4ERR_INVAL if bits other than those defined above are set in a SETATTR, CREATE, OPEN, VERIFY or NVERIFY operation.

6.3. Common Methods

The requirements in this section will be referred to in future sections, especially Section 6.4.

6.3.1. Interpreting an ACL

6.3.1.1. Server Considerations

The server uses the algorithm described in Section 6.2.1 to determine whether an ACL allows access to an object. However, the ACL may not be the sole determiner of access. For example:

- In the case of a file system exported as read-only, the server may deny write permissions even though an object's ACL grants it.

- Server implementations MAY grant ACE4_WRITE_ACL and ACE4_READ_ACL permissions to prevent a situation from arising in which there is no valid way to ever modify the ACL.

- All servers will allow a user the ability to read the data of the file when only the execute permission is granted (i.e., If the ACL denies the user the ACE4_READ_DATA access and allows the user ACE4_EXECUTE, the server will allow the user to read the data of the file).

- Many servers have the notion of owner-override in which the owner of the object is allowed to override accesses that are denied by the ACL. This may be helpful, for example, to allow users continued access to open files on which the permissions have changed.

- Many servers have the notion of a "superuser" that has privileges beyond an ordinary user. The superuser may be able to read or write data or metadata in ways that would not be permitted by the ACL.

6.3.1.2. Client Considerations

Clients SHOULD NOT do their own access checks based on their interpretation the ACL, but rather use the OPEN and ACCESS operations to do access checks. This allows the client to act on the results of having the server determine whether or not access should be granted based on its interpretation of the ACL.

Clients must be aware of situations in which an object's ACL will define a certain access even though the server will not enforce it. In general, but especially in these situations, the client needs to do its part in the enforcement of access as defined by the ACL. To do this, the client MAY send the appropriate ACCESS operation prior to servicing the request of the user or application in order to determine whether the user or application should be granted the access requested. For examples in which the ACL may define accesses that the server doesn't enforce see Section 6.3.1.1.

6.3.2. Computing a Mode Attribute from an ACL

The following method can be used to calculate the MODE4_R*, MODE4_W* and MODE4_X* bits of a mode attribute, based upon an ACL.

First, for each of the special identifiers OWNER@, GROUP@, and EVERYONE@, evaluate the ACL in order, considering only ALLOW and DENY ACEs for the identifier EVERYONE@ and for the identifier under consideration. The result of the evaluation will be an NFSv4 ACL mask showing exactly which bits are permitted to that identifier.

Then translate the calculated mask for OWNER@, GROUP@, and EVERYONE@ into mode bits for, respectively, the user, group, and other, as

follows:

1. Set the read bit (MODE4_RUSR, MODE4_RGRP, or MODE4_ROTH) if and only if ACE4_READ_DATA is set in the corresponding mask.

2. Set the write bit (MODE4_WUSR, MODE4_WGRP, or MODE4_WOTH) if and only if ACE4_WRITE_DATA and ACE4_APPEND_DATA are both set in the corresponding mask.

3. Set the execute bit (MODE4_XUSR, MODE4_XGRP, or MODE4_XOTH), if and only if ACE4_EXECUTE is set in the corresponding mask.

6.3.2.1. Discussion

Some server implementations also add bits permitted to named users and groups to the group bits (MODE4_RGRP, MODE4_WGRP, and MODE4_XGRP).

Implementations are discouraged from doing this, because it has been found to cause confusion for users who see members of a file's group denied access that the mode bits appear to allow. (The presence of DENY ACEs may also lead to such behavior, but DENY ACEs are expected to be more rarely used.)

The same user confusion seen when fetching the mode also results if setting the mode does not effectively control permissions for the owner, group, and other users; this motivates some of the requirements that follow.

6.4. Requirements

The server that supports both mode and ACL must take care to synchronize the MODE4_*USR, MODE4_*GRP, and MODE4_*OTH bits with the ACEs which have respective who fields of "OWNER@", "GROUP@", and "EVERYONE@" so that the client can see semantically equivalent access permissions exist whether the client asks for owner, owner_group and mode attributes, or for just the ACL.

In this section, much is made of the methods in Section 6.3.2. Many requirements refer to this section. But note that the methods have behaviors specified with "SHOULD". This is intentional, to avoid invalidating existing implementations that compute the mode according to the withdrawn POSIX ACL draft (1003.1e draft 17), rather than by actual permissions on owner, group, and other.

6.4.1. Setting the mode and/or ACL Attributes

6.4.1.1. Setting mode and not ACL

When any of the nine low-order mode bits are changed because the mode attribute was set, and no ACL attribute is explicitly set, the acl attribute must be modified in accordance with the updated value of those bits. This must happen even if the value of the low-order bits is the same after the mode is set as before.

Note that any AUDIT or ALARM ACEs are unaffected by changes to the mode.

In cases in which the permissions bits are subject to change, the acl attribute MUST be modified such that the mode computed via the method in Section 6.3.2 yields the low-order nine bits (MODE4_R*, MODE4_W*, MODE4_X*) of the mode attribute as modified by the attribute change. The ACL attributes SHOULD also be modified such that:

1. If MODE4_RGRP is not set, entities explicitly listed in the ACL other than OWNER@ and EVERYONE@ SHOULD NOT be granted ACE4_READ_DATA.

2. If MODE4_WGRP is not set, entities explicitly listed in the ACL other than OWNER@ and EVERYONE@ SHOULD NOT be granted ACE4_WRITE_DATA or ACE4_APPEND_DATA.

3. If MODE4_XGRP is not set, entities explicitly listed in the ACL other than OWNER@ and EVERYONE@ SHOULD NOT be granted ACE4_EXECUTE.

Access mask bits other those listed above, appearing in ALLOW ACEs, MAY also be disabled.

Note that ACEs with the flag ACE4_INHERIT_ONLY_ACE set do not affect the permissions of the ACL itself, nor do ACEs of the type AUDIT and ALARM. As such, it is desirable to leave these ACEs unmodified when modifying the ACL attributes.

Also note that the requirement may be met by discarding the acl in favor of an ACL that represents the mode and only the mode. This is permitted, but it is preferable for a server to preserve as much of the ACL as possible without violating the above requirements. Discarding the ACL makes it effectively impossible for a file created with a mode attribute to inherit an ACL (see Section 6.4.3).

6.4.1.2. Setting ACL and not mode

When setting the acl and not setting the mode attribute, the permission bits of the mode need to be derived from the ACL. In this case, the ACL attribute SHOULD be set as given. The nine low-order bits of the mode attribute (MODE4_R*, MODE4_W*, MODE4_X*) MUST be modified to match the result of the method Section 6.3.2. The three high-order bits of the mode (MODE4_SUID, MODE4_SGID, MODE4_SVTX) SHOULD remain unchanged.

6.4.1.3. Setting both ACL and mode

When setting both the mode and the acl attribute in the same operation, the attributes MUST be applied in this order: mode, then ACL. The mode-related attribute is set as given, then the ACL attribute is set as given, possibly changing the final mode, as described above in Section 6.4.1.2.

6.4.2. Retrieving the mode and/or ACL Attributes

This section applies only to servers that support both the mode and ACL attributes.

Some server implementations may have a concept of "objects without ACLs", meaning that all permissions are granted and denied according to the mode attribute, and that no ACL attribute is stored for that object. If an ACL attribute is requested of such a server, the server SHOULD return an ACL that does not conflict with the mode; that is to say, the ACL returned SHOULD represent the nine low-order bits of the mode attribute (MODE4_R*, MODE4_W*, MODE4_X*) as described in Section 6.3.2.

For other server implementations, the ACL attribute is always present for every object. Such servers SHOULD store at least the three high-order bits of the mode attribute (MODE4_SUID, MODE4_SGID, MODE4_SVTX). The server SHOULD return a mode attribute if one is requested, and the low-order nine bits of the mode (MODE4_R*, MODE4_W*, MODE4_X*) MUST match the result of applying the method in Section 6.3.2 to the ACL attribute.

6.4.3. Creating New Objects

If a server supports any ACL attributes, it may use the ACL attributes on the parent directory to compute an initial ACL attribute for a newly created object. This will be referred to as the inherited ACL within this section. The act of adding one or more ACEs to the inherited ACL that are based upon ACEs in the parent directory's ACL will be referred to as inheriting an ACE within this

section.

Implementors should standardize on what the behavior of CREATE and OPEN must be depending on the presence or absence of the mode and ACL attributes.

1. If just the mode is given in the call:

   In this case, inheritance SHOULD take place, but the mode MUST be applied to the inherited ACL as described in Section 6.4.1.1, thereby modifying the ACL.

2. If just the ACL is given in the call:

   In this case, inheritance SHOULD NOT take place, and the ACL as defined in the CREATE or OPEN will be set without modification, and the mode modified as in Section 6.4.1.2

3. If both mode and ACL are given in the call:

   In this case, inheritance SHOULD NOT take place, and both attributes will be set as described in Section 6.4.1.3.

4. If neither mode nor ACL are given in the call:

   In the case where an object is being created without any initial attributes at all, e.g., an OPEN operation with an opentype4 of OPEN4_CREATE and a createmode4 of EXCLUSIVE4, inheritance SHOULD NOT take place. Instead, the server SHOULD set permissions to deny all access to the newly created object. It is expected that the appropriate client will set the desired attributes in a subsequent SETATTR operation, and the server SHOULD allow that operation to succeed, regardless of what permissions the object is created with. For example, an empty ACL denies all permissions, but the server should allow the owner's SETATTR to succeed even though WRITE_ACL is implicitly denied.

   In other cases, inheritance SHOULD take place, and no modifications to the ACL will happen. The mode attribute, if supported, MUST be as computed in Section 6.3.2, with the MODE4_SUID, MODE4_SGID and MODE4_SVTX bits clear. If no inheritable ACEs exist on the parent directory, the rules for creating acl attributes are implementation defined.

6.4.3.1. The Inherited ACL

If the object being created is not a directory, the inherited ACL SHOULD NOT inherit ACEs from the parent directory ACL unless the ACE4_FILE_INHERIT_FLAG is set.

If the object being created is a directory, the inherited ACL should inherit all inheritable ACEs from the parent directory, those that have ACE4_FILE_INHERIT_ACE or ACE4_DIRECTORY_INHERIT_ACE flag set. If the inheritable ACE has ACE4_FILE_INHERIT_ACE set, but ACE4_DIRECTORY_INHERIT_ACE is clear, the inherited ACE on the newly created directory MUST have the ACE4_INHERIT_ONLY_ACE flag set to prevent the directory from being affected by ACEs meant for non-directories.

When a new directory is created, the server MAY split any inherited ACE which is both inheritable and effective (in other words, which has neither ACE4_INHERIT_ONLY_ACE nor ACE4_NO_PROPAGATE_INHERIT_ACE set), into two ACEs, one with no inheritance flags, and one with ACE4_INHERIT_ONLY_ACE set. This makes it simpler to modify the effective permissions on the directory without modifying the ACE which is to be inherited to the new directory's children.

7. Multi-Server Namespace

NFSv4 supports attributes that allow a namespace to extend beyond the boundaries of a single server. It is RECOMMENDED that clients and servers support construction of such multi-server namespaces. Use of such multi-server namespaces is OPTIONAL, however, and for many purposes, single-server namespaces are perfectly acceptable. Use of multi-server namespaces can provide many advantages, however, by separating a file system's logical position in a namespace from the (possibly changing) logistical and administrative considerations that result in particular file systems being located on particular servers.

7.1. Location Attributes

NFSv4 contains RECOMMENDED attributes that allow file systems on one server to be associated with one or more instances of that file system on other servers. These attributes specify such file system instances by specifying a server address target (either as a DNS name representing one or more IP addresses or as a literal IP address) together with the path of that file system within the associated single-server namespace.

The fs_locations RECOMMENDED attribute allows specification of the

file system locations where the data corresponding to a given file system may be found.

7.2. File System Presence or Absence

A given location in an NFSv4 namespace (typically but not necessarily a multi-server namespace) can have a number of file system instance locations associated with it via the fs_locations attribute. There may also be an actual current file system at that location, accessible via normal namespace operations (e.g., LOOKUP). In this case, the file system is said to be "present" at that position in the namespace, and clients will typically use it, reserving use of additional locations specified via the location-related attributes to situations in which the principal location is no longer available.

When there is no actual file system at the namespace location in question, the file system is said to be "absent". An absent file system contains no files or directories other than the root. Any reference to it, except to access a small set of attributes useful in determining alternate locations, will result in an error, NFS4ERR_MOVED. Note that if the server ever returns the error NFS4ERR_MOVED, it MUST support the fs_locations attribute.

While the error name suggests that we have a case of a file system that once was present, and has only become absent later, this is only one possibility. A position in the namespace may be permanently absent with the set of file system(s) designated by the location attributes being the only realization. The name NFS4ERR_MOVED reflects an earlier, more limited conception of its function, but this error will be returned whenever the referenced file system is absent, whether it has moved or not.

Except in the case of GETATTR-type operations (to be discussed later), when the current filehandle at the start of an operation is within an absent file system, that operation is not performed and the error NFS4ERR_MOVED is returned, to indicate that the file system is absent on the current server.

Because a GETFH cannot succeed if the current filehandle is within an absent file system, filehandles within an absent file system cannot be transferred to the client. When a client does have filehandles within an absent file system, it is the result of obtaining them when the file system was present, and having the file system become absent subsequently.

It should be noted that because the check for the current filehandle being within an absent file system happens at the start of every operation, operations that change the current filehandle so that it

is within an absent file system will not result in an error. This allows such combinations as PUTFH-GETATTR and LOOKUP-GETATTR to be used to get attribute information, particularly location attribute information, as discussed below.

7.3. Getting Attributes for an Absent File System

When a file system is absent, most attributes are not available, but it is necessary to allow the client access to the small set of attributes that are available, and most particularly that which gives information about the correct current locations for this file system, fs_locations.

7.3.1. GETATTR Within an Absent File System

As mentioned above, an exception is made for GETATTR in that attributes may be obtained for a filehandle within an absent file system. This exception only applies if the attribute mask contains at least the fs_locations attribute bit, which indicates the client is interested in a result regarding an absent file system. If it is not requested, GETATTR will result in an NFS4ERR_MOVED error.

When a GETATTR is done on an absent file system, the set of supported attributes is very limited. Many attributes, including those that are normally REQUIRED, will not be available on an absent file system. In addition to the fs_locations attribute, the following attributes SHOULD be available on absent file systems. In the case of RECOMMENDED attributes, they should be available at least to the same degree that they are available on present file systems.

fsid: This attribute should be provided so that the client can determine file system boundaries, including, in particular, the boundary between present and absent file systems. This value must be different from any other fsid on the current server and need have no particular relationship to fsids on any particular destination to which the client might be directed.

mounted_on_fileid: For objects at the top of an absent file system, this attribute needs to be available. Since the fileid is within the present parent file system, there should be no need to reference the absent file system to provide this information.

Other attributes SHOULD NOT be made available for absent file systems, even when it is possible to provide them. The server should not assume that more information is always better and should avoid gratuitously providing additional information.

When a GETATTR operation includes a bit mask for the attribute

fs_locations, but where the bit mask includes attributes that are not supported, GETATTR will not return an error, but will return the mask of the actual attributes supported with the results.

Handling of VERIFY/NVERIFY is similar to GETATTR in that if the attribute mask does not include fs_locations the error NFS4ERR_MOVED will result. It differs in that any appearance in the attribute mask of an attribute not supported for an absent file system (and note that this will include some normally REQUIRED attributes) will also cause an NFS4ERR_MOVED result.

7.3.2. READDIR and Absent File Systems

A READDIR performed when the current filehandle is within an absent file system will result in an NFS4ERR_MOVED error, since, unlike the case of GETATTR, no such exception is made for READDIR.

Attributes for an absent file system may be fetched via a READDIR for a directory in a present file system, when that directory contains the root directories of one or more absent file systems. In this case, the handling is as follows:

- If the attribute set requested includes fs_locations, then fetching of attributes proceeds normally and no NFS4ERR_MOVED indication is returned, even when the rdattr_error attribute is requested.

- If the attribute set requested does not include fs_locations, then if the rdattr_error attribute is requested, each directory entry for the root of an absent file system will report NFS4ERR_MOVED as the value of the rdattr_error attribute.

- If the attribute set requested does not include either of the attributes fs_locations or rdattr_error then the occurrence of the root of an absent file system within the directory will result in the READDIR failing with an NFS4ERR_MOVED error.

- The unavailability of an attribute because of a file system's absence, even one that is ordinarily REQUIRED, does not result in any error indication. The set of attributes returned for the root directory of the absent file system in that case is simply restricted to those actually available.

7.4. Uses of Location Information

The location-bearing attribute of fs_locations provides, together with the possibility of absent file systems, a number of important facilities in providing reliable, manageable, and scalable data

access.

When a file system is present, these attributes can provide alternative locations, to be used to access the same data, in the event of server failures, communications problems, or other difficulties that make continued access to the current file system impossible or otherwise impractical. Under some circumstances, multiple alternative locations may be used simultaneously to provide higher-performance access to the file system in question. Provision of such alternate locations is referred to as "replication" although there are cases in which replicated sets of data are not in fact present, and the replicas are instead different paths to the same data.

When a file system is present and becomes absent, clients can be given the opportunity to have continued access to their data, at an alternate location. In this case, a continued attempt to use the data in the now-absent file system will result in an NFS4ERR_MOVED error and, at that point, the successor locations (typically only one although multiple choices are possible) can be fetched and used to continue access. Transfer of the file system contents to the new location is referred to as "migration", but it should be kept in mind that there are cases in which this term can be used, like "replication", when there is no actual data migration per se.

Where a file system was not previously present, specification of file system location provides a means by which file systems located on one server can be associated with a namespace defined by another server, thus allowing a general multi-server namespace facility. A designation of such a location, in place of an absent file system, is called a "referral".

Because client support for location-related attributes is OPTIONAL, a server may (but is not required to) take action to hide migration and referral events from such clients, by acting as a proxy, for example.

7.4.1. File System Replication

The fs_locations attribute provides alternative locations, to be used to access data in place of or in addition to the current file system instance. On first access to a file system, the client should obtain the value of the set of alternate locations by interrogating the fs_locations attribute.

In the event that server failures, communications problems, or other difficulties make continued access to the current file system impossible or otherwise impractical, the client can use the alternate locations as a way to get continued access to its data. Multiple

locations may be used simultaneously, to provide higher performance through the exploitation of multiple paths between client and target file system.

The alternate locations may be physical replicas of the (typically read-only) file system data, or they may reflect alternate paths to the same server or provide for the use of various forms of server clustering in which multiple servers provide alternate ways of accessing the same physical file system. How these different modes of file system transition are represented within the fs_locations attribute and how the client deals with file system transition issues will be discussed in detail below.

Multiple server addresses, whether they are derived from a single entry with a DNS name representing a set of IP addresses or from multiple entries each with its own server address, may correspond to the same actual server.

7.4.2. File System Migration

When a file system is present and becomes absent, clients can be given the opportunity to have continued access to their data, at an alternate location, as specified by the fs_locations attribute. Typically, a client will be accessing the file system in question, get an NFS4ERR_MOVED error, and then use the fs_locations attribute to determine the new location of the data.

Such migration can be helpful in providing load balancing or general resource reallocation. The protocol does not specify how the file system will be moved between servers. It is anticipated that a number of different server-to-server transfer mechanisms might be used with the choice left to the server implementor. The NFSv4 protocol specifies the method used to communicate the migration event between client and server.

The new location may be an alternate communication path to the same server or, in the case of various forms of server clustering, another server providing access to the same physical file system. The client's responsibilities in dealing with this transition depend on the specific nature of the new access path as well as how and whether data was in fact migrated. These issues will be discussed in detail below.

When an alternate location is designated as the target for migration, it must designate the same data. Where file systems are writable, a change made on the original file system must be visible on all migration targets. Where a file system is not writable but represents a read-only copy (possibly periodically updated) of a

writable file system, similar requirements apply to the propagation of updates. Any change visible in the original file system must already be effected on all migration targets, to avoid any possibility that a client, in effecting a transition to the migration target, will see any reversion in file system state.

7.4.3. Referrals

Referrals provide a way of placing a file system in a location within the namespace essentially without respect to its physical location on a given server. This allows a single server or a set of servers to present a multi-server namespace that encompasses file systems located on multiple servers. Some likely uses of this include establishment of site-wide or organization-wide namespaces, or even knitting such together into a truly global namespace.

Referrals occur when a client determines, upon first referencing a position in the current namespace, that it is part of a new file system and that the file system is absent. When this occurs, typically by receiving the error NFS4ERR_MOVED, the actual location or locations of the file system can be determined by fetching the fs_locations attribute.

The locations-related attribute may designate a single file system location or multiple file system locations, to be selected based on the needs of the client.

Use of multi-server namespaces is enabled by NFSv4 but is not required. The use of multi-server namespaces and their scope will depend on the applications used and system administration preferences.

Multi-server namespaces can be established by a single server providing a large set of referrals to all of the included file systems. Alternatively, a single multi-server namespace may be administratively segmented with separate referral file systems (on separate servers) for each separately administered portion of the namespace. The top-level referral file system or any segment may use replicated referral file systems for higher availability.

Generally, multi-server namespaces are for the most part uniform, in that the same data made available to one client at a given location in the namespace is made available to all clients at that location.

7.5. Location Entries and Server Identity

As mentioned above, a single location entry may have a server address target in the form of a DNS name that may represent multiple IP

addresses, while multiple location entries may have their own server address targets that reference the same server.

When multiple addresses for the same server exist, the client may assume that for each file system in the namespace of a given server network address, there exist file systems at corresponding namespace locations for each of the other server network addresses. It may do this even in the absence of explicit listing in fs_locations. Such corresponding file system locations can be used as alternate locations, just as those explicitly specified via the fs_locations attribute.

If a single location entry designates multiple server IP addresses, the client cannot assume that these addresses are multiple paths to the same server. In most cases, they will be, but the client MUST verify that before acting on that assumption. When two server addresses are designated by a single location entry and they correspond to different servers, this normally indicates some sort of misconfiguration, and so the client should avoid using such location entries when alternatives are available. When they are not, clients should pick one of IP addresses and use it, without using others that are not directed to the same server.

7.6. Additional Client-Side Considerations

When clients make use of servers that implement referrals, replication, and migration, care should be taken that a user who mounts a given file system that includes a referral or a relocated file system continues to see a coherent picture of that user-side file system despite the fact that it contains a number of server-side file systems that may be on different servers.

One important issue is upward navigation from the root of a server-side file system to its parent (specified as ".." in UNIX), in the case in which it transitions to that file system as a result of referral, migration, or a transition as a result of replication. When the client is at such a point, and it needs to ascend to the parent, it must go back to the parent as seen within the multi-server namespace rather than sending a LOOKUPP operation to the server, which would result in the parent within that server's single-server namespace. In order to do this, the client needs to remember the filehandles that represent such file system roots and use these instead of issuing a LOOKUPP operation to the current server. This will allow the client to present to applications a consistent namespace, where upward navigation and downward navigation are consistent.

Another issue concerns refresh of referral locations. When referrals

are used extensively, they may change as server configurations change. It is expected that clients will cache information related to traversing referrals so that future client-side requests are resolved locally without server communication. This is usually rooted in client-side name look up caching. Clients should periodically purge this data for referral points in order to detect changes in location information.

A problem exists if a client allows an open owner to have state on multiple filesystems on a server. If one of those filesystems is migrated, what happens to the sequence numbers? A client can avoid such a situation with the stipulation that any client which supports migration MUST ensure that any open owner is confined to a single filesystem. If the server finds itself migrating open owners that span multiple filesystems, then it MUST not migrate the state for the conflicting open owners on the non-migrated filesystems; instead it MUST return NFS4ERR_STALE_STATEID if the client tries to use those stateids.

7.7. Effecting File System Transitions

Transitions between file system instances, whether due to switching between replicas upon server unavailability or to server-initiated migration events, are best dealt with together. This is so even though, for the server, pragmatic considerations will normally force different implementation strategies for planned and unplanned transitions. Even though the prototypical use cases of replication and migration contain distinctive sets of features, when all possibilities for these operations are considered, there is an underlying unity of these operations, from the client's point of view, that makes treating them together desirable.

A number of methods are possible for servers to replicate data and to track client state in order to allow clients to transition between file system instances with a minimum of disruption. Such methods vary between those that use inter-server clustering techniques to limit the changes seen by the client, to those that are less aggressive, use more standard methods of replicating data, and impose a greater burden on the client to adapt to the transition.

The NFSv4 protocol does not impose choices on clients and servers with regard to that spectrum of transition methods. In fact, there are many valid choices, depending on client and application requirements and their interaction with server implementation choices. The NFSv4.0 protocol does not provide the servers a means of communicating the transition methods. In the NFSv4.1 protocol [31], an additional attribute "fs_locations_info" is presented, which will define the specific choices that can be made, how these choices

are communicated to the client, and how the client is to deal with any discontinuities.

In the sections below, references will be made to various possible server implementation choices as a way of illustrating the transition scenarios that clients may deal with. The intent here is not to define or limit server implementations but rather to illustrate the range of issues that clients may face. Again, as the NFSv4.0 protocol does not have an explicit means of communicating these issues to the client, the intent is to document the problems that can be faced in a multi-server name space and allow the client to use the inferred transitions available via fs_locations and other attributes (see Section 7.9.1).

In the discussion below, references will be made to a file system having a particular property or to two file systems (typically the source and destination) belonging to a common class of any of several types. Two file systems that belong to such a class share some important aspects of file system behavior that clients may depend upon when present, to easily effect a seamless transition between file system instances. Conversely, where the file systems do not belong to such a common class, the client has to deal with various sorts of implementation discontinuities that may cause performance or other issues in effecting a transition.

While fs_locations is available, default assumptions with regard to such classifications have to be inferred (see Section 7.9.1 for details).

In cases in which one server is expected to accept opaque values from the client that originated from another server, the servers SHOULD encode the "opaque" values in big-endian byte order. If this is done, servers acting as replicas or immigrating file systems will be able to parse values like stateids, directory cookies, filehandles, etc., even if their native byte order is different from that of other servers cooperating in the replication and migration of the file system.

7.7.1. File System Transitions and Simultaneous Access

When a single file system may be accessed at multiple locations, either because of an indication of file system identity as reported by the fs_locations attribute, the client will, depending on specific circumstances as discussed below, either:

- Access multiple instances simultaneously, each of which represents an alternate path to the same data and metadata.

- Accesses one instance (or set of instances) and then transition to an alternative instance (or set of instances) as a result of network issues, server unresponsiveness, or server-directed migration.

7.7.2. Filehandles and File System Transitions

There are a number of ways in which filehandles can be handled across a file system transition. These can be divided into two broad classes depending upon whether the two file systems across which the transition happens share sufficient state to effect some sort of continuity of file system handling.

When there is no such cooperation in filehandle assignment, the two file systems are reported as being in different handle classes. In this case, all filehandles are assumed to expire as part of the file system transition. Note that this behavior does not depend on fh_expire_type attribute and depends on the specification of the FH4_VOL_MIGRATION bit.

When there is co-operation in filehandle assignment, the two file systems are reported as being in the same handle classes. In this case, persistent filehandles remain valid after the file system transition, while volatile filehandles (excluding those that are only volatile due to the FH4_VOL_MIGRATION bit) are subject to expiration on the target server.

7.7.3. Fileids and File System Transitions

The issue of continuity of fileids in the event of a file system transition needs to be addressed. The general expectation is that in situations in which the two file system instances are created by a single vendor using some sort of file system image copy, fileids will be consistent across the transition, while in the analogous multi-vendor transitions they will not. This poses difficulties, especially for the client without special knowledge of the transition mechanisms adopted by the server. Note that although fileid is not a REQUIRED attribute, many servers support fileids and many clients provide APIs that depend on fileids.

It is important to note that while clients themselves may have no trouble with a fileid changing as a result of a file system transition event, applications do typically have access to the fileid (e.g., via stat). The result is that an application may work perfectly well if there is no file system instance transition or if any such transition is among instances created by a single vendor, yet be unable to deal with the situation in which a multi-vendor transition occurs at the wrong time.

Providing the same fileids in a multi-vendor (multiple server vendors) environment has generally been held to be quite difficult. While there is work to be done, it needs to be pointed out that this difficulty is partly self-imposed. Servers have typically identified fileid with inode number, i.e., with a quantity used to find the file in question. This identification poses special difficulties for migration of a file system between vendors where assigning the same index to a given file may not be possible. Note here that a fileid is not required to be useful to find the file in question, only that it is unique within the given file system. Servers prepared to accept a fileid as a single piece of metadata and store it apart from the value used to index the file information can relatively easily maintain a fileid value across a migration event, allowing a truly transparent migration event.

In any case, where servers can provide continuity of fileids, they should, and the client should be able to find out that such continuity is available and take appropriate action. Information about the continuity (or lack thereof) of fileids across a file system transition is represented by specifying whether the file systems in question are of the same fileid class.

Note that when consistent fileids do not exist across a transition (either because there is no continuity of fileids or because fileid is not a supported attribute on one of instances involved), and there are no reliable filehandles across a transition event (either because there is no filehandle continuity or because the filehandles are volatile), the client is in a position where it cannot verify that files it was accessing before the transition are the same objects. It is forced to assume that no object has been renamed, and, unless there are guarantees that provide this (e.g., the file system is read-only), problems for applications may occur. Therefore, use of such configurations should be limited to situations where the problems that this may cause can be tolerated.

7.7.4. Fsids and File System Transitions

Since fsids are generally only unique within a per-server basis, it is likely that they will change during a file system transition. Clients should not make the fsids received from the server visible to applications since they may not be globally unique, and because they may change during a file system transition event. Applications are best served if they are isolated from such transitions to the extent possible.

7.7.5. The Change Attribute and File System Transitions

Since the change attribute is defined as a server-specific one, change attributes fetched from one server are normally presumed to be invalid on another server. Such a presumption is troublesome since it would invalidate all cached change attributes, requiring refetching. Even more disruptive, the absence of any assured continuity for the change attribute means that even if the same value is retrieved on refetch, no conclusions can be drawn as to whether the object in question has changed. The identical change attribute could be merely an artifact of a modified file with a different change attribute construction algorithm, with that new algorithm just happening to result in an identical change value.

When the two file systems have consistent change attribute formats, and we say that they are in the same change class, the client may assume a continuity of change attribute construction and handle this situation just as it would be handled without any file system transition.

7.7.6. Lock State and File System Transitions

In a file system transition, the client needs to handle cases in which the two servers have cooperated in state management and in which they have not. Cooperation by two servers in state management requires coordination of client IDs. Before the client attempts to use a client ID associated with one server in a request to the server of the other file system, it must eliminate the possibility that two non-cooperating servers have assigned the same client ID by accident.

In the case of migration, the servers involved in the migration of a file system SHOULD transfer all server state from the original to the new server. When this is done, it must be done in a way that is transparent to the client. With replication, such a degree of common state is typically not the case.

This state transfer will reduce disruption to the client when a file system transition occurs. If the servers are successful in transferring all state, then the client may use the existing stateids associated with that client ID for the old file system instance in connection with that same client ID in connection with the transitioned file system instance.

File systems cooperating in state management may actually share state or simply divide the identifier space so as to recognize (and reject as stale) each other's stateids and client IDs. Servers that do share state may not do so under all conditions or at all times. If the server cannot be sure when accepting a client ID that it reflects

the locks the client was given, the server must treat all associated state as stale and report it as such to the client.

The client must establish a new client ID on the destination, if it does not have one already, and reclaim locks if allowed by the server. In this case, old stateids and client IDs should not be presented to the new server since there is no assurance that they will not conflict with IDs valid on that server.

When actual locks are not known to be maintained, the destination server may establish a grace period specific to the given file system, with non-reclaim locks being rejected for that file system, even though normal locks are being granted for other file systems. Clients should not infer the absence of a grace period for file systems being transitioned to a server from responses to requests for other file systems.

In the case of lock reclamation for a given file system after a file system transition, edge conditions can arise similar to those for reclaim after server restart (although in the case of the planned state transfer associated with migration, these can be avoided by securely recording lock state as part of state migration). Unless the destination server can guarantee that locks will not be incorrectly granted, the destination server should not allow lock reclaims and should avoid establishing a grace period. (See Section 9.14 for further details.)

Servers are encouraged to provide facilities to allow locks to be reclaimed on the new server after a file system transition. Often such facilities may not be available and client should be prepared to re-obtain locks, even though it is possible that the client may have its LOCK or OPEN request denied due to a conflicting lock.

The consequences of having no facilities available to reclaim locks on the new server will depend on the type of environment. In some environments, such as the transition between read-only file systems, such denial of locks should not pose large difficulties in practice. When an attempt to re-establish a lock on a new server is denied, the client should treat the situation as if its original lock had been revoked. Note that when the lock is granted, the client cannot assume that no conflicting lock could have been granted in the interim. Where change attribute continuity is present, the client may check the change attribute to check for unwanted file modifications. Where even this is not available, and the file system is not read-only, a client may reasonably treat all pending locks as having been revoked.

7.7.6.1. Transitions and the Lease_time Attribute

In order that the client may appropriately manage its lease in the case of a file system transition, the destination server must establish proper values for the lease_time attribute.

When state is transferred transparently, that state should include the correct value of the lease_time attribute. The lease_time attribute on the destination server must never be less than that on the source, since this would result in premature expiration of a lease granted by the source server. Upon transitions in which state is transferred transparently, the client is under no obligation to refetch the lease_time attribute and may continue to use the value previously fetched (on the source server).

If state has not been transferred transparently because the client ID is rejected when presented to the new server, the client should fetch the value of lease_time on the new (i.e., destination) server, and use it for subsequent locking requests. However, the server must respect a grace period of at least as long as the lease_time on the source server, in order to ensure that clients have ample time to reclaim their lock before potentially conflicting non-reclaimed locks are granted.

7.7.7. Write Verifiers and File System Transitions

In a file system transition, the two file systems may be clustered in the handling of unstably written data. When this is the case, and the two file systems belong to the same write-verifier class, write verifiers returned from one system may be compared to those returned by the other and superfluous writes avoided.

When two file systems belong to different write-verifier classes, any verifier generated by one must not be compared to one provided by the other. Instead, it should be treated as not equal even when the values are identical.

7.7.8. Readdir Cookies and Verifiers and File System Transitions

In a file system transition, the two file systems may be consistent in their handling of READDIR cookies and verifiers. When this is the case, and the two file systems belong to the same readdir class, READDIR cookies and verifiers from one system may be recognized by the other and READDIR operations started on one server may be validly continued on the other, simply by presenting the cookie and verifier returned by a READDIR operation done on the first file system to the second.

When two file systems belong to different readdir classes, any READDIR cookie and verifier generated by one is not valid on the second, and must not be presented to that server by the client. The client should act as if the verifier was rejected.

7.7.9. File System Data and File System Transitions

When multiple replicas exist and are used simultaneously or in succession by a client, applications using them will normally expect that they contain either the same data or data that is consistent with the normal sorts of changes that are made by other clients updating the data of the file system (with metadata being the same to the degree inferred by the fs_locations attribute). However, when multiple file systems are presented as replicas of one another, the precise relationship between the data of one and the data of another is not, as a general matter, specified by the NFSv4 protocol. It is quite possible to present as replicas file systems where the data of those file systems is sufficiently different that some applications have problems dealing with the transition between replicas. The namespace will typically be constructed so that applications can choose an appropriate level of support, so that in one position in the namespace a varied set of replicas will be listed, while in another only those that are up-to-date may be considered replicas. The protocol does define four special cases of the relationship among replicas to be specified by the server and relied upon by clients:

- When multiple server addresses correspond to the same actual server, the client may depend on the fact that changes to data, metadata, or locks made on one file system are immediately reflected on others.

- When multiple replicas exist and are used simultaneously by a client, they must designate the same data. Where file systems are writable, a change made on one instance must be visible on all instances, immediately upon the earlier of the return of the modifying requester or the visibility of that change on any of the associated replicas. This allows a client to use these replicas simultaneously without any special adaptation to the fact that there are multiple replicas. In this case, locks (whether share reservations or byte-range locks), and delegations obtained on one replica are immediately reflected on all replicas, even though these locks will be managed under a set of client IDs.

- When one replica is designated as the successor instance to another existing instance after return NFS4ERR_MOVED (i.e., the case of migration), the client may depend on the fact that all changes written to stable storage on the original instance are written to stable storage of the successor (uncommitted writes are

dealt with in Section 7.7.7).

- Where a file system is not writable but represents a read-only copy (possibly periodically updated) of a writable file system, clients have similar requirements with regard to the propagation of updates. They may need a guarantee that any change visible on the original file system instance must be immediately visible on any replica before the client transitions access to that replica, in order to avoid any possibility that a client, in effecting a transition to a replica, will see any reversion in file system state. Since these file systems are presumed to be unsuitable for simultaneous use, there is no specification of how locking is handled; in general, locks obtained on one file system will be separate from those on others. Since these are going to be read-only file systems, this is not expected to pose an issue for clients or applications.

7.8. Effecting File System Referrals

Referrals are effected when an absent file system is encountered, and one or more alternate locations are made available by the fs_locations attribute. The client will typically get an NFS4ERR_MOVED error, fetch the appropriate location information, and proceed to access the file system on a different server, even though it retains its logical position within the original namespace. Referrals differ from migration events in that they happen only when the client has not previously referenced the file system in question (so there is nothing to transition). Referrals can only come into effect when an absent file system is encountered at its root.

The examples given in the sections below are somewhat artificial in that an actual client will not typically do a multi-component look up, but will have cached information regarding the upper levels of the name hierarchy. However, these example are chosen to make the required behavior clear and easy to put within the scope of a small number of requests, without getting unduly into details of how specific clients might choose to cache things.

7.8.1. Referral Example (LOOKUP)

Let us suppose that the following COMPOUND is sent in an environment in which /this/is/the/path is absent from the target server. This may be for a number of reasons. It may be the case that the file system has moved, or it may be the case that the target server is functioning mainly, or solely, to refer clients to the servers on which various file systems are located.

- PUTROOTFH
- LOOKUP "this"
- LOOKUP "is"
- LOOKUP "the"
- LOOKUP "path"
- GETFH
- GETATTR(fsid,fileid,size,time_modify)

Under the given circumstances, the following will be the result.

- PUTROOTFH --> NFS_OK. The current fh is now the root of the pseudo-fs.
- LOOKUP "this" --> NFS_OK. The current fh is for /this and is within the pseudo-fs.
- LOOKUP "is" --> NFS_OK. The current fh is for /this/is and is within the pseudo-fs.
- LOOKUP "the" --> NFS_OK. The current fh is for /this/is/the and is within the pseudo-fs.
- LOOKUP "path" --> NFS_OK. The current fh is for /this/is/the/path and is within a new, absent file system, but ... the client will never see the value of that fh.
- GETFH --> NFS4ERR_MOVED. Fails because current fh is in an absent file system at the start of the operation, and the specification makes no exception for GETFH.
- GETATTR(fsid,fileid,size,time_modify) Not executed because the failure of the GETFH stops processing of the COMPOUND.

Given the failure of the GETFH, the client has the job of determining the root of the absent file system and where to find that file system, i.e., the server and path relative to that server's root fh. Note here that in this example, the client did not obtain filehandles and attribute information (e.g., fsid) for the intermediate directories, so that it would not be sure where the absent file system starts. It could be the case, for example, that /this/is/the is the root of the moved file system and that the reason that the look up of "path" succeeded is that the file system was not absent on

that operation but was moved between the last LOOKUP and the GETFH (since COMPOUND is not atomic). Even if we had the fsids for all of the intermediate directories, we could have no way of knowing that /this/is/the/path was the root of a new file system, since we don't yet have its fsid.

In order to get the necessary information, let us re-send the chain of LOOKUPs with GETFHs and GETATTRs to at least get the fsids so we can be sure where the appropriate file system boundaries are. The client could choose to get fs_locations at the same time but in most cases the client will have a good guess as to where file system boundaries are (because of where NFS4ERR_MOVED was, and was not, received) making fetching of fs_locations unnecessary.

OP01: PUTROOTFH --> NFS_OK

- Current fh is root of pseudo-fs.

OP02: GETATTR(fsid) --> NFS_OK

- Just for completeness. Normally, clients will know the fsid of the pseudo-fs as soon as they establish communication with a server.

OP03: LOOKUP "this" --> NFS_OK

OP04: GETATTR(fsid) --> NFS_OK

- Get current fsid to see where file system boundaries are. The fsid will be that for the pseudo-fs in this example, so no boundary.

OP05: GETFH --> NFS_OK

- Current fh is for /this and is within pseudo-fs.

OP06: LOOKUP "is" --> NFS_OK

- Current fh is for /this/is and is within pseudo-fs.

OP07: GETATTR(fsid) --> NFS_OK

- Get current fsid to see where file system boundaries are. The fsid will be that for the pseudo-fs in this example, so no boundary.

OP08: GETFH --> NFS_OK

- Current fh is for /this/is and is within pseudo-fs.

OP09: LOOKUP "the" --> NFS_OK

- Current fh is for /this/is/the and is within pseudo-fs.

OP10: GETATTR(fsid) --> NFS_OK

- Get current fsid to see where file system boundaries are. The fsid will be that for the pseudo-fs in this example, so no boundary.

OP11: GETFH --> NFS_OK

- Current fh is for /this/is/the and is within pseudo-fs.

OP12: LOOKUP "path" --> NFS_OK

- Current fh is for /this/is/the/path and is within a new, absent file system, but ...

- The client will never see the value of that fh.

OP13: GETATTR(fsid, fs_locations) --> NFS_OK

- We are getting the fsid to know where the file system boundaries are. In this operation, the fsid will be different than that of the parent directory (which in turn was retrieved in OP10). Note that the fsid we are given will not necessarily be preserved at the new location. That fsid might be different, and in fact the fsid we have for this file system might be a valid fsid of a different file system on that new server.

- In this particular case, we are pretty sure anyway that what has moved is /this/is/the/path rather than /this/is/the since we have the fsid of the latter and it is that of the pseudo-fs, which presumably cannot move. However, in other examples, we might not have this kind of information to rely on (e.g., /this/is/the might be a non-pseudo file system separate from /this/is/the/path), so we need to have other reliable source information on the boundary of the file system that is moved. If, for example, the file system /this/is had moved, we would have a case of migration rather than referral, and once the boundaries of the migrated file system was clear we could fetch fs_locations.

- We are fetching fs_locations because the fact that we got an NFS4ERR_MOVED at this point means that it is most likely that this is a referral and we need the destination. Even if it is the case that /this/is/the is a file system that has migrated, we will still need the location information for that file system.

OP14: GETFH --> NFS4ERR_MOVED

- Fails because current fh is in an absent file system at the start of the operation, and the specification makes no exception for GETFH. Note that this means the server will never send the client a filehandle from within an absent file system.

Given the above, the client knows where the root of the absent file system is (/this/is/the/path) by noting where the change of fsid occurred (between "the" and "path"). The fs_locations attribute also gives the client the actual location of the absent file system, so that the referral can proceed. The server gives the client the bare minimum of information about the absent file system so that there will be very little scope for problems of conflict between information sent by the referring server and information of the file system's home. No filehandles and very few attributes are present on the referring server, and the client can treat those it receives as transient information with the function of enabling the referral.

7.8.2. Referral Example (READDIR)

Another context in which a client may encounter referrals is when it does a READDIR on a directory in which some of the sub-directories are the roots of absent file systems.

Suppose such a directory is read as follows:

- PUTROOTFH
- LOOKUP "this"
- LOOKUP "is"
- LOOKUP "the"
- READDIR (fsid, size, time_modify, mounted_on_fileid)

In this case, because rdattr_error is not requested, fs_locations is not requested, and some of the attributes cannot be provided, the result will be an NFS4ERR_MOVED error on the READDIR, with the detailed results as follows:

- PUTROOTFH --> NFS_OK. The current fh is at the root of the pseudo-fs.

- LOOKUP "this" --> NFS_OK. The current fh is for /this and is within the pseudo-fs.

- LOOKUP "is" --> NFS_OK. The current fh is for /this/is and is within the pseudo-fs.

- LOOKUP "the" --> NFS_OK. The current fh is for /this/is/the and is within the pseudo-fs.

- READDIR (fsid, size, time_modify, mounted_on_fileid) --> NFS4ERR_MOVED. Note that the same error would have been returned if /this/is/the had migrated, but it is returned because the directory contains the root of an absent file system.

So now suppose that we re-send with rdattr_error:

- PUTROOTFH

- LOOKUP "this"

- LOOKUP "is"

- LOOKUP "the"

- READDIR (rdattr_error, fsid, size, time_modify, mounted_on_fileid)

The results will be:

- PUTROOTFH --> NFS_OK. The current fh is at the root of the pseudo-fs.

- LOOKUP "this" --> NFS_OK. The current fh is for /this and is within the pseudo-fs.

- LOOKUP "is" --> NFS_OK. The current fh is for /this/is and is within the pseudo-fs.

- LOOKUP "the" --> NFS_OK. The current fh is for /this/is/the and is within the pseudo-fs.

- READDIR (rdattr_error, fsid, size, time_modify, mounted_on_fileid) --> NFS_OK. The attributes for directory entry with the component named "path" will only contain rdattr_error with the value NFS4ERR_MOVED, together with an fsid value and a value for mounted_on_fileid.

So suppose we do another READDIR to get fs_locations (although we could have used a GETATTR directly, as in Section 7.8.1).

- PUTROOTFH
- LOOKUP "this"
- LOOKUP "is"
- LOOKUP "the"
- READDIR (rdattr_error, fs_locations, mounted_on_fileid, fsid, size, time_modify)

The results would be:

- PUTROOTFH --> NFS_OK. The current fh is at the root of the pseudo-fs.
- LOOKUP "this" --> NFS_OK. The current fh is for /this and is within the pseudo-fs.
- LOOKUP "is" --> NFS_OK. The current fh is for /this/is and is within the pseudo-fs.
- LOOKUP "the" --> NFS_OK. The current fh is for /this/is/the and is within the pseudo-fs.
- READDIR (rdattr_error, fs_locations, mounted_on_fileid, fsid, size, time_modify) --> NFS_OK. The attributes will be as shown below.

The attributes for the directory entry with the component named "path" will only contain:

- rdattr_error (value: NFS_OK)
- fs_locations
- mounted_on_fileid (value: unique fileid within referring file system)
- fsid (value: unique value within referring server)

The attributes for entry "path" will not contain size or time_modify because these attributes are not available within an absent file system.

7.9. The Attribute fs_locations

The fs_locations attribute is structured in the following way:

```
struct fs_location4 {
        utf8val_REQUIRED4       server<>;
        pathname4               rootpath;
};


struct fs_locations4 {
        pathname4       fs_root;
        fs_location4    locations<>;
};
```

The fs_location4 data type is used to represent the location of a file system by providing a server name and the path to the root of the file system within that server's namespace. When a set of servers have corresponding file systems at the same path within their namespaces, an array of server names may be provided. An entry in the server array is a UTF-8 string and represents one of a traditional DNS host name, IPv4 address, IPv6 address, or an zero-length string. A zero-length string SHOULD be used to indicate the current address being used for the RPC call. It is not a requirement that all servers that share the same rootpath be listed in one fs_location4 instance. The array of server names is provided for convenience. Servers that share the same rootpath may also be listed in separate fs_location4 entries in the fs_locations attribute.

The fs_locations4 data type and fs_locations attribute contain an array of such locations. Since the namespace of each server may be constructed differently, the "fs_root" field is provided. The path represented by fs_root represents the location of the file system in the current server's namespace, i.e., that of the server from which the fs_locations attribute was obtained. The fs_root path is meant to aid the client by clearly referencing the root of the file system whose locations are being reported, no matter what object within the current file system the current filehandle designates. The fs_root is simply the pathname the client used to reach the object on the current server (i.e., the object to which the fs_locations attribute applies).

When the fs_locations attribute is interrogated and there are no alternate file system locations, the server SHOULD return a zero-length array of fs_location4 structures, together with a valid fs_root.

As an example, suppose there is a replicated file system located at two servers (servA and servB). At servA, the file system is located at path /a/b/c. At, servB the file system is located at path /x/y/z. If the client were to obtain the fs_locations value for the directory at /a/b/c/d, it might not necessarily know that the file system's root is located in servA's namespace at /a/b/c. When the client switches to servB, it will need to determine that the directory it first referenced at servA is now represented by the path /x/y/z/d on servB. To facilitate this, the fs_locations attribute provided by servA would have an fs_root value of /a/b/c and two entries in fs_locations. One entry in fs_locations will be for itself (servA) and the other will be for servB with a path of /x/y/z. With this information, the client is able to substitute /x/y/z for the /a/b/c at the beginning of its access path and construct /x/y/z/d to use for the new server.

Note that: there is no requirement that the number of components in each rootpath be the same; there is no relation between the number of components in rootpath or fs_root, and none of the components in each rootpath and fs_root have to be the same. In the above example, we could have had a third element in the locations array, with server equal to "servC", and rootpath equal to "/I/II", and a fourth element in locations with server equal to "servD" and rootpath equal to "/aleph/beth/gimel/daleth/he".

The relationship between fs_root to a rootpath is that the client replaces the pathname indicated in fs_root for the current server for the substitute indicated in rootpath for the new server.

For an example of a referred or migrated file system, suppose there is a file system located at serv1. At serv1, the file system is located at /az/buky/vedi/glagoli. The client finds that object at glagoli has migrated (or is a referral). The client gets the fs_locations attribute, which contains an fs_root of /az/buky/vedi/glagoli, and one element in the locations array, with server equal to serv2, and rootpath equal to /izhitsa/fita. The client replaces /az/buky/vedi/glagoli with /izhitsa/fita, and uses the latter pathname on serv2.

Thus, the server MUST return an fs_root that is equal to the path the client used to reach the object to which the fs_locations attribute applies. Otherwise, the client cannot determine the new path to use on the new server.

7.9.1. Inferring Transition Modes

When fs_locations is used, information about the specific locations should be assumed based on the following rules.

The following rules are general and apply irrespective of the context.

- All listed file system instances should be considered as of the same handle class if and only if the current fh_expire_type attribute does not include the FH4_VOL_MIGRATION bit. Note that in the case of referral, filehandle issues do not apply since there can be no filehandles known within the current file system nor is there any access to the fh_expire_type attribute on the referring (absent) file system.

- All listed file system instances should be considered as of the same fileid class if and only if the fh_expire_type attribute indicates persistent filehandles and does not include the FH4_VOL_MIGRATION bit. Note that in the case of referral, fileid issues do not apply since there can be no fileids known within the referring (absent) file system nor is there any access to the fh_expire_type attribute.

- All file system instances servers should be considered as of different change classes.

- All file system instances servers should be considered as of different readdir classes.

For other class assignments, handling of file system transitions depends on the reasons for the transition:

- When the transition is due to migration, that is, the client was directed to a new file system after receiving an NFS4ERR_MOVED error, the target should be treated as being of the same write-verifier class as the source.

- When the transition is due to failover to another replica, that is, the client selected another replica without receiving and NFS4ERR_MOVED error, the target should be treated as being of a different write-verifier class from the source.

The specific choices reflect typical implementation patterns for failover and controlled migration, respectively.

See Section 17 for a discussion on the recommendations for the security flavor to be used by any GETATTR operation that requests the "fs_locations" attribute.

8. NFS Server Name Space

8.1. Server Exports

On a UNIX server the name space describes all the files reachable by pathnames under the root directory or "/". On a Windows NT server the name space constitutes all the files on disks named by mapped disk letters. NFS server administrators rarely make the entire server's filesystem name space available to NFS clients. More often portions of the name space are made available via an "export" feature. In previous versions of the NFS protocol, the root filehandle for each export is obtained through the MOUNT protocol; the client sends a string that identifies the export of name space and the server returns the root filehandle for it. The MOUNT protocol supports an EXPORTS procedure that will enumerate the server's exports.

8.2. Browsing Exports

The NFSv4 protocol provides a root filehandle that clients can use to obtain filehandles for these exports via a multi-component LOOKUP. A common user experience is to use a graphical user interface (perhaps a file "Open" dialog window) to find a file via progressive browsing through a directory tree. The client must be able to move from one export to another export via single-component, progressive LOOKUP operations.

This style of browsing is not well supported by the NFSv2 and NFSv3 protocols. The client expects all LOOKUP operations to remain within a single server filesystem. For example, the device attribute will not change. This prevents a client from taking name space paths that span exports.

An automounter on the client can obtain a snapshot of the server's name space using the EXPORTS procedure of the MOUNT protocol. If it understands the server's pathname syntax, it can create an image of the server's name space on the client. The parts of the name space that are not exported by the server are filled in with a "pseudo filesystem" that allows the user to browse from one mounted filesystem to another. There is a drawback to this representation of the server's name space on the client: it is static. If the server administrator adds a new export the client will be unaware of it.

8.3. Server Pseudo Filesystem

NFSv4 servers avoid this name space inconsistency by presenting all the exports within the framework of a single server name space. An NFSv4 client uses LOOKUP and READDIR operations to browse seamlessly

from one export to another. Portions of the server name space that are not exported are bridged via a "pseudo filesystem" that provides a view of exported directories only. A pseudo filesystem has a unique fsid and behaves like a normal, read only filesystem.

Based on the construction of the server's name space, it is possible that multiple pseudo filesystems may exist. For example,

```
/a          pseudo filesystem
/a/b        real filesystem
/a/b/c      pseudo filesystem
/a/b/c/d    real filesystem
```

Each of the pseudo filesystems are considered separate entities and therefore will have a unique fsid.

8.4. Multiple Roots

The DOS and Windows operating environments are sometimes described as having "multiple roots". Filesystems are commonly represented as disk letters. MacOS represents filesystems as top level names. NFSv4 servers for these platforms can construct a pseudo file system above these root names so that disk letters or volume names are simply directory names in the pseudo root.

8.5. Filehandle Volatility

The nature of the server's pseudo filesystem is that it is a logical representation of filesystem(s) available from the server. Therefore, the pseudo filesystem is most likely constructed dynamically when the server is first instantiated. It is expected that the pseudo filesystem may not have an on disk counterpart from which persistent filehandles could be constructed. Even though it is preferable that the server provide persistent filehandles for the pseudo filesystem, the NFS client should expect that pseudo file system filehandles are volatile. This can be confirmed by checking the associated "fh_expire_type" attribute for those filehandles in question. If the filehandles are volatile, the NFS client must be prepared to recover a filehandle value (e.g., with a multi-component LOOKUP) when receiving an error of NFS4ERR_FHEXPIRED.

8.6. Exported Root

If the server's root filesystem is exported, one might conclude that a pseudo-filesystem is not needed. This would be wrong. Assume the following filesystems on a server:

```
/       disk1  (exported)
/a      disk2  (not exported)
/a/b    disk3  (exported)
```

Because disk2 is not exported, disk3 cannot be reached with simple LOOKUPs. The server must bridge the gap with a pseudo-filesystem.

8.7. Mount Point Crossing

The server filesystem environment may be constructed in such a way that one filesystem contains a directory which is 'covered' or mounted upon by a second filesystem. For example:

```
/a/b            (filesystem 1)
/a/b/c/d        (filesystem 2)
```

The pseudo filesystem for this server may be constructed to look like:

```
/               (place holder/not exported)
/a/b            (filesystem 1)
/a/b/c/d        (filesystem 2)
```

It is the server's responsibility to present the pseudo filesystem that is complete to the client. If the client sends a lookup request for the path "/a/b/c/d", the server's response is the filehandle of the filesystem "/a/b/c/d". In previous versions of the NFS protocol, the server would respond with the filehandle of directory "/a/b/c/d" within the filesystem "/a/b".

The NFS client will be able to determine if it crosses a server mount point by a change in the value of the "fsid" attribute.

8.8. Security Policy and Name Space Presentation

The application of the server's security policy needs to be carefully considered by the implementor. One may choose to limit the viewability of portions of the pseudo filesystem based on the server's perception of the client's ability to authenticate itself properly. However, with the support of multiple security mechanisms and the ability to negotiate the appropriate use of these mechanisms, the server is unable to properly determine if a client will be able to authenticate itself. If, based on its policies, the server chooses to limit the contents of the pseudo filesystem, the server may effectively hide filesystems from a client that may otherwise have legitimate access.

As suggested practice, the server should apply the security policy of

a shared resource in the server's namespace to the components of the resource's ancestors. For example:

```
/
/a/b
/a/b/c
```

The /a/b/c directory is a real filesystem and is the shared resource. The security policy for /a/b/c is Kerberos with integrity. The server should apply the same security policy to /, /a, and /a/b. This allows for the extension of the protection of the server's namespace to the ancestors of the real shared resource.

For the case of the use of multiple, disjoint security mechanisms in the server's resources, the security for a particular object in the server's namespace should be the union of all security mechanisms of all direct descendants.

9. File Locking and Share Reservations

Integrating locking into the NFS protocol necessarily causes it to be stateful. With the inclusion of share reservations the protocol becomes substantially more dependent on state than the traditional combination of NFS and NLM (Network Lock Manager) [32]. There are three components to making this state manageable:

- clear division between client and server
- ability to reliably detect inconsistency in state between client and server
- simple and robust recovery mechanisms

In this model, the server owns the state information. The client requests changes in locks and the server responds with the changes made. Non-client-initiated changes in locking state are infrequent. The client receives prompt notification of such changes and can adjust its view of the locking state to reflect the server's changes.

Individual pieces of state created by the server and passed to the client at its request are represented by 128-bit stateids. These stateids may represent a particular open file, a set of byte-range locks held by a particular owner, or a recallable delegation of privileges to access a file in particular ways or at a particular location.

In all cases, there is a transition from the most general information

that represents a client as a whole to the eventual lightweight stateid used for most client and server locking interactions. The details of this transition will vary with the type of object but it always starts with a client ID.

To support Win32 share reservations it is necessary to atomically OPEN or CREATE files. Having a separate share/unshare operation would not allow correct implementation of the Win32 OpenFile API. In order to correctly implement share semantics, the previous NFS protocol mechanisms used when a file is opened or created (LOOKUP, CREATE, ACCESS) need to be replaced. The NFSv4 protocol has an OPEN operation that subsumes the NFSv3 methodology of LOOKUP, CREATE, and ACCESS. However, because many operations require a filehandle, the traditional LOOKUP is preserved to map a file name to filehandle without establishing state on the server. The policy of granting access or modifying files is managed by the server based on the client's state. These mechanisms can implement policy ranging from advisory only locking to full mandatory locking.

9.1. Opens and Byte-Range Locks

It is assumed that manipulating a byte-range lock is rare when compared to READ and WRITE operations. It is also assumed that server restarts and network partitions are relatively rare. Therefore it is important that the READ and WRITE operations have a lightweight mechanism to indicate if they possess a held lock. A byte-range lock request contains the heavyweight information required to establish a lock and uniquely define the owner of the lock.

The following sections describe the transition from the heavy weight information to the eventual stateid used for most client and server locking and lease interactions.

9.1.1. Client ID

For each LOCK request, the client must identify itself to the server. This is done in such a way as to allow for correct lock identification and crash recovery. A sequence of a SETCLIENTID operation followed by a SETCLIENTID_CONFIRM operation is required to establish the identification onto the server. Establishment of identification by a new incarnation of the client also has the effect of immediately breaking any leased state that a previous incarnation of the client might have had on the server, as opposed to forcing the new client incarnation to wait for the leases to expire. Breaking the lease state amounts to the server removing all lock, share reservation, and, where the server is not supporting the CLAIM_DELEGATE_PREV claim type, all delegation state associated with same client with the same identity. For discussion of delegation

state recovery, see Section 10.2.1.

Owners of opens and owners of byte-range locks are separate entities and remain separate even if the same opaque arrays are used to designate owners of each. The protocol distinguishes between open-owners (represented by open_owner4 structures) and lock-owners (represented by lock_owner4 structures).

Both sorts of owners consist of a clientid and an opaque owner string. For each client, the set of distinct owner values used with that client constitutes the set of owners of that type, for the given client.

Each open is associated with a specific open-owner while each byte-range lock is associated with a lock-owner and an open-owner, the latter being the open-owner associated with the open file under which the LOCK operation was done.

Client identification is encapsulated in the following structure:

```
struct nfs_client_id4 {
        verifier4       verifier;
        opaque          id<NFS4_OPAQUE_LIMIT>;
};
```

The first field, verifier is a client incarnation verifier that is used to detect client reboots. Only if the verifier is different from that which the server has previously recorded the client (as identified by the second field of the structure, id) does the server start the process of canceling the client's leased state.

The second field, id is a variable length string that uniquely defines the client.

There are several considerations for how the client generates the id string:

- The string should be unique so that multiple clients do not present the same string. The consequences of two clients presenting the same string range from one client getting an error to one client having its leased state abruptly and unexpectedly canceled.

- The string should be selected so the subsequent incarnations (e.g., reboots) of the same client cause the client to present the same string. The implementor is cautioned against an approach that requires the string to be recorded in a local file because this precludes the use of the implementation in an environment

where there is no local disk and all file access is from an NFSv4 server.

- The string should be different for each server network address that the client accesses, rather than common to all server network addresses. The reason is that it may not be possible for the client to tell if the same server is listening on multiple network addresses. If the client issues SETCLIENTID with the same id string to each network address of such a server, the server will think it is the same client, and each successive SETCLIENTID will cause the server to begin the process of removing the client's previous leased state.

- The algorithm for generating the string should not assume that the client's network address won't change. This includes changes between client incarnations and even changes while the client is stilling running in its current incarnation. This means that if the client includes just the client's and server's network address in the id string, there is a real risk, after the client gives up the network address, that another client, using a similar algorithm for generating the id string, will generate a conflicting id string.

Given the above considerations, an example of a well generated id string is one that includes:

- The server's network address.

- The client's network address.

- For a user level NFSv4 client, it should contain additional information to distinguish the client from other user level clients running on the same host, such as an universally unique identifier (UUID).

- Additional information that tends to be unique, such as one or more of:

  * The client machine's serial number (for privacy reasons, it is best to perform some one way function on the serial number).

  * A MAC address.

  * The timestamp of when the NFSv4 software was first installed on the client (though this is subject to the previously mentioned caution about using information that is stored in a file, because the file might only be accessible over NFSv4).

* A true random number. However since this number ought to be the same between client incarnations, this shares the same problem as that of the using the timestamp of the software installation.

As a security measure, the server MUST NOT cancel a client's leased state if the principal that established the state for a given id string is not the same as the principal issuing the SETCLIENTID.

Note that SETCLIENTID and SETCLIENTID_CONFIRM has a secondary purpose of establishing the information the server needs to make callbacks to the client for purpose of supporting delegations. It is permitted to change this information via SETCLIENTID and SETCLIENTID_CONFIRM within the same incarnation of the client without removing the client's leased state.

Once a SETCLIENTID and SETCLIENTID_CONFIRM sequence has successfully completed, the client uses the shorthand client identifier, of type clientid4, instead of the longer and less compact nfs_client_id4 structure. This shorthand client identifier (a client ID) is assigned by the server and should be chosen so that it will not conflict with a client ID previously assigned by the server. This applies across server restarts or reboots. When a client ID is presented to a server and that client ID is not recognized, as would happen after a server reboot, the server will reject the request with the error NFS4ERR_STALE_CLIENTID. When this happens, the client must obtain a new client ID by use of the SETCLIENTID operation and then proceed to any other necessary recovery for the server reboot case (See Section 9.6.2).

The client must also employ the SETCLIENTID operation when it receives a NFS4ERR_STALE_STATEID error using a stateid derived from its current client ID, since this also indicates a server reboot which has invalidated the existing client ID (see Section 9.1.4 for details).

See the detailed descriptions of SETCLIENTID and SETCLIENTID_CONFIRM for a complete specification of the operations.

9.1.2. Server Release of Client ID

If the server determines that the client holds no associated state for its client ID, the server may choose to release the client ID. The server may make this choice for an inactive client so that resources are not consumed by those intermittently active clients. If the client contacts the server after this release, the server must ensure the client receives the appropriate error so that it will use the SETCLIENTID/SETCLIENTID_CONFIRM sequence to establish a new

identity. It should be clear that the server must be very hesitant to release a client ID since the resulting work on the client to recover from such an event will be the same burden as if the server had failed and restarted. Typically a server would not release a client ID unless there had been no activity from that client for many minutes.

Note that if the id string in a SETCLIENTID request is properly constructed, and if the client takes care to use the same principal for each successive use of SETCLIENTID, then, barring an active denial of service attack, NFS4ERR_CLID_INUSE should never be returned.

However, client bugs, server bugs, or perhaps a deliberate change of the principal owner of the id string (such as the case of a client that changes security flavors, and under the new flavor, there is no mapping to the previous owner) will in rare cases result in NFS4ERR_CLID_INUSE.

In that event, when the server gets a SETCLIENTID for a client ID that currently has no state, or it has state, but the lease has expired, rather than returning NFS4ERR_CLID_INUSE, the server MUST allow the SETCLIENTID, and confirm the new client ID if followed by the appropriate SETCLIENTID_CONFIRM.

9.1.3. Stateid Definition

When the server grants a lock of any type (including opens, byte-range locks, and delegations), it responds with a unique stateid that represents a set of locks (often a single lock) for the same file, of the same type, and sharing the same ownership characteristics. Thus, opens of the same file by different open-owners each have an identifying stateid. Similarly, each set of byte-range locks on a file owned by a specific lock-owner has its own identifying stateid. Delegations also have associated stateids by which they may be referenced. The stateid is used as a shorthand reference to a lock or set of locks, and given a stateid, the server can determine the associated state-owner or state-owners (in the case of an open-owner/lock-owner pair) and the associated filehandle. When stateids are used, the current filehandle must be the one associated with that stateid.

All stateids associated with a given client ID are associated with a common lease that represents the claim of those stateids and the objects they represent to be maintained by the server. See Section 9.5 for a discussion of the lease.

Each stateid must be unique to the server. Many operations take a

stateid as an argument but not a clientid, so the server must be able to infer the client from the stateid.

9.1.3.1. Stateid Types

With the exception of special stateids (see Section 9.1.3.3), each stateid represents locking objects of one of a set of types defined by the NFSv4 protocol. Note that in all these cases, where we speak of guarantee, it is understood there are situations such as a client restart, or lock revocation, that allow the guarantee to be voided.

- Stateids may represent opens of files.

  Each stateid in this case represents the OPEN state for a given client ID/open-owner/filehandle triple. Such stateids are subject to change (with consequent incrementing of the stateid's seqid) in response to OPENs that result in upgrade and OPEN_DOWNGRADE operations.

- Stateids may represent sets of byte-range locks.

  All locks held on a particular file by a particular owner and all gotten under the aegis of a particular open file are associated with a single stateid with the seqid being incremented whenever LOCK and LOCKU operations affect that set of locks.

- Stateids may represent file delegations, which are recallable guarantees by the server to the client, that other clients will not reference, or will not modify a particular file, until the delegation is returned.

  A stateid represents a single delegation held by a client for a particular filehandle.

9.1.3.2. Stateid Structure

Stateids are divided into two fields, a 96-bit "other" field identifying the specific set of locks and a 32-bit "seqid" sequence value. Except in the case of special stateids (see Section 9.1.3.3), a particular value of the "other" field denotes a set of locks of the same type (for example, byte-range locks, opens, or delegations), for a specific file or directory, and sharing the same ownership characteristics. The seqid designates a specific instance of such a set of locks, and is incremented to indicate changes in such a set of locks, either by the addition or deletion of locks from the set, a change in the byte-range they apply to, or an upgrade or downgrade in the type of one or more locks.

When such a set of locks is first created, the server SHOULD return a stateid with seqid value of one. On subsequent operations that modify the set of locks, the server is required to increment the "seqid" field by one whenever it returns a stateid for the same state-owner/file/type combination and there is some change in the set of locks actually designated. In this case, the server will return a stateid with an "other" field the same as previously used for that state-owner/file/type combination, with an incremented "seqid" field. This pattern continues until the seqid is incremented past NFS4_UINT32_MAX, and one (not zero) SHOULD be the next seqid value. The purpose of the incrementing of the seqid is to allow the server to communicate to the client the order in which operations that modified locking state associated with a stateid have been processed.

In making comparisons between seqids, both by the client in determining the order of operations and by the server in determining whether the NFS4ERR_OLD_STATEID is to be returned, the possibility of the seqid being swapped around past the NFS4_UINT32_MAX value needs to be taken into account.

9.1.3.3. Special Stateids

Stateid values whose "other" field is either all zeros or all ones are reserved. They may not be assigned by the server but have special meanings defined by the protocol. The particular meaning depends on whether the "other" field is all zeros or all ones and the specific value of the "seqid" field.

The following combinations of "other" and "seqid" are defined in NFSv4:

- When "other" and "seqid" are both zero, the stateid is treated as a special anonymous stateid, which can be used in READ, WRITE, and SETATTR requests to indicate the absence of any open state associated with the request. When an anonymous stateid value is used, and an existing open denies the form of access requested, then access will be denied to the request.

- When "other" and "seqid" are both all ones, the stateid is a special READ bypass stateid. When this value is used in WRITE or SETATTR, it is treated like the anonymous value. When used in READ, the server MAY grant access, even if access would normally be denied to READ requests.

If a stateid value is used which has all zero or all ones in the "other" field, but does not match one of the cases above, the server MUST return the error NFS4ERR_BAD_STATEID.

Special stateids, unlike other stateids, are not associated with individual client IDs or filehandles and can be used with all valid client IDs and filehandles.

9.1.3.4. Stateid Lifetime and Validation

Stateids must remain valid until either a client restart or a server restart or until the client returns all of the locks associated with the stateid by means of an operation such as CLOSE or DELEGRETURN. If the locks are lost due to revocation as long as the client ID is valid, the stateid remains a valid designation of that revoked state. Stateids associated with byte-range locks are an exception. They remain valid even if a LOCKU frees all remaining locks, so long as the open file with which they are associated remains open.

It should be noted that there are situations in which the client's locks become invalid, without the client requesting they be returned. These include lease expiration and a number of forms of lock revocation within the lease period. It is important to note that in these situations, the stateid remains valid and the client can use it to determine the disposition of the associated lost locks.

An "other" value must never be reused for a different purpose (i.e. different filehandle, owner, or type of locks) within the context of a single client ID. A server may retain the "other" value for the same purpose beyond the point where it may otherwise be freed but if it does so, it must maintain "seqid" continuity with previous values.

One mechanism that may be used to satisfy the requirement that the server recognize invalid and out-of-date stateids is for the server to divide the "other" field of the stateid into two fields.

- An index into a table of locking-state structures.
- A generation number which is incremented on each allocation of a table entry for a particular use.

And then store in each table entry,

- The client ID with which the stateid is associated.
- The current generation number for the (at most one) valid stateid sharing this index value.
- The filehandle of the file on which the locks are taken.
- An indication of the type of stateid (open, byte-range lock, file delegation).

- The last "seqid" value returned corresponding to the current "other" value.

- An indication of the current status of the locks associated with this stateid. In particular, whether these have been revoked and if so, for what reason.

With this information, an incoming stateid can be validated and the appropriate error returned when necessary. Special and non-special stateids are handled separately. (See Section 9.1.3.3 for a discussion of special stateids.)

When a stateid is being tested, and the "other" field is all zeros or all ones, a check that the "other" and "seqid" fields match a defined combination for a special stateid is done and the results determined as follows:

- If the "other" and "seqid" fields do not match a defined combination associated with a special stateid, the error NFS4ERR_BAD_STATEID is returned.

- If the combination is valid in general but is not appropriate to the context in which the stateid is used (e.g., an all-zero stateid is used when an open stateid is required in a LOCK operation), the error NFS4ERR_BAD_STATEID is also returned.

- Otherwise, the check is completed and the special stateid is accepted as valid.

When a stateid is being tested, and the "other" field is neither all zeros or all ones, the following procedure could be used to validate an incoming stateid and return an appropriate error, when necessary, assuming that the "other" field would be divided into a table index and an entry generation.

- If the table index field is outside the range of the associated table, return NFS4ERR_BAD_STATEID.

- If the selected table entry is of a different generation than that specified in the incoming stateid, return NFS4ERR_BAD_STATEID.

- If the selected table entry does not match the current filehandle, return NFS4ERR_BAD_STATEID.

- If the stateid represents revoked state or state lost as a result of lease expiration, then return NFS4ERR_EXPIRED, NFS4ERR_BAD_STATEID, or NFS4ERR_ADMIN_REVOKED, as appropriate.

- If the stateid type is not valid for the context in which the stateid appears, return NFS4ERR_BAD_STATEID. Note that a stateid may be valid in general, but be invalid for a particular operation, as, for example, when a stateid which doesn't represent byte-range locks is passed to the non-from_open case of LOCK or to LOCKU, or when a stateid which does not represent an open is passed to CLOSE or OPEN_DOWNGRADE. In such cases, the server MUST return NFS4ERR_BAD_STATEID.

- If the "seqid" field is not zero, and it is greater than the current sequence value corresponding the current "other" field, return NFS4ERR_BAD_STATEID.

- If the "seqid" field is less than the current sequence value corresponding the current "other" field, return NFS4ERR_OLD_STATEID.

- Otherwise, the stateid is valid and the table entry should contain any additional information about the type of stateid and information associated with that particular type of stateid, such as the associated set of locks, such as open-owner and lock-owner information, as well as information on the specific locks, such as open modes and byte ranges.

9.1.3.5. Stateid Use for I/O Operations

Clients performing I/O operations need to select an appropriate stateid based on the locks (including opens and delegations) held by the client and the various types of state-owners sending the I/O requests. SETATTR operations that change the file size are treated like I/O operations in this regard.

The following rules, applied in order of decreasing priority, govern the selection of the appropriate stateid. In following these rules, the client will only consider locks of which it has actually received notification by an appropriate operation response or callback.

- If the client holds a delegation for the file in question, the delegation stateid SHOULD be used.

- Otherwise, if the entity corresponding to the lock-owner (e.g., a process) sending the I/O has a byte-range lock stateid for the associated open file, then the byte-range lock stateid for that lock-owner and open file SHOULD be used.

- If there is no byte-range lock stateid, then the OPEN stateid for the current open-owner, and that OPEN stateid for the open file in question SHOULD be used.

- Finally, if none of the above apply, then a special stateid SHOULD be used.

Ignoring these rules may result in situations in which the server does not have information necessary to properly process the request. For example, when mandatory byte-range locks are in effect, if the stateid does not indicate the proper lock-owner, via a lock stateid, a request might be avoidably rejected.

The server however should not try to enforce these ordering rules and should use whatever information is available to properly process I/O requests. In particular, when a client has a delegation for a given file, it SHOULD take note of this fact in processing a request, even if it is sent with a special stateid.

9.1.3.6. Stateid Use for SETATTR Operations

In the case of SETATTR operations, a stateid is present. In cases other than those that set the file size, the client may send either a special stateid or, when a delegation is held for the file in question, a delegation stateid. While the server SHOULD validate the stateid and may use the stateid to optimize the determination as to whether a delegation is held, it SHOULD note the presence of a delegation even when a special stateid is sent, and MUST accept a valid delegation stateid when sent.

9.1.4. lock-owner

When requesting a lock, the client must present to the server the client ID and an identifier for the owner of the requested lock. These two fields are referred to as the lock-owner and the definition of those fields are:

- A client ID returned by the server as part of the client's use of the SETCLIENTID operation.

- A variable length opaque array used to uniquely define the owner of a lock managed by the client.

  This may be a thread id, process id, or other unique value.

When the server grants the lock, it responds with a unique stateid. The stateid is used as a shorthand reference to the lock-owner, since the server will be maintaining the correspondence between them.

9.1.5. Use of the Stateid and Locking

All READ, WRITE and SETATTR operations contain a stateid. For the purposes of this section, SETATTR operations which change the size attribute of a file are treated as if they are writing the area between the old and new size (i.e., the range truncated or added to the file by means of the SETATTR), even where SETATTR is not explicitly mentioned in the text. The stateid passed to one of these operations must be one that represents an OPEN (e.g., via the open-owner), a set of byte-range locks, or a delegation, or it may be a special stateid representing anonymous access or the special bypass stateid.

If the state-owner performs a READ or WRITE in a situation in which it has established a lock or share reservation on the server (any OPEN constitutes a share reservation) the stateid (previously returned by the server) must be used to indicate what locks, including both byte-range locks and share reservations, are held by the state-owner. If no state is established by the client, either byte-range lock or share reservation, a stateid of all bits 0 is used. Regardless whether a stateid of all bits 0, or a stateid returned by the server is used, if there is a conflicting share reservation or mandatory byte-range lock held on the file, the server MUST refuse to service the READ or WRITE operation.

Share reservations are established by OPEN operations and by their nature are mandatory in that when the OPEN denies READ or WRITE operations, that denial results in such operations being rejected with error NFS4ERR_LOCKED. Byte-range locks may be implemented by the server as either mandatory or advisory, or the choice of mandatory or advisory behavior may be determined by the server on the basis of the file being accessed (for example, some UNIX-based servers support a "mandatory lock bit" on the mode attribute such that if set, byte-range locks are required on the file before I/O is possible). When byte-range locks are advisory, they only prevent the granting of conflicting lock requests and have no effect on READs or WRITEs. Mandatory byte-range locks, however, prevent conflicting I/O operations. When they are attempted, they are rejected with NFS4ERR_LOCKED. When the client gets NFS4ERR_LOCKED on a file it knows it has the proper share reservation for, it will need to issue a LOCK request on the region of the file that includes the region the I/O was to be performed on, with an appropriate locktype (i.e., READ*_LT for a READ operation, WRITE*_LT for a WRITE operation).

With NFSv3, there was no notion of a stateid so there was no way to tell if the application process of the client sending the READ or WRITE operation had also acquired the appropriate byte-range lock on the file. Thus there was no way to implement mandatory locking.

With the stateid construct, this barrier has been removed.

Note that for UNIX environments that support mandatory file locking, the distinction between advisory and mandatory locking is subtle. In fact, advisory and mandatory byte-range locks are exactly the same in so far as the APIs and requirements on implementation. If the mandatory lock attribute is set on the file, the server checks to see if the lock-owner has an appropriate shared (read) or exclusive (write) byte-range lock on the region it wishes to read or write to. If there is no appropriate lock, the server checks if there is a conflicting lock (which can be done by attempting to acquire the conflicting lock on the behalf of the lock-owner, and if successful, release the lock after the READ or WRITE is done), and if there is, the server returns NFS4ERR_LOCKED.

For Windows environments, there are no advisory byte-range locks, so the server always checks for byte-range locks during I/O requests.

Thus, the NFSv4 LOCK operation does not need to distinguish between advisory and mandatory byte-range locks. It is the NFS version 4 server's processing of the READ and WRITE operations that introduces the distinction.

Every stateid other than the special stateid values noted in this section, whether returned by an OPEN-type operation (i.e., OPEN, OPEN_DOWNGRADE), or by a LOCK-type operation (i.e., LOCK or LOCKU), defines an access mode for the file (i.e., READ, WRITE, or READ-WRITE) as established by the original OPEN which began the stateid sequence, and as modified by subsequent OPENs and OPEN_DOWNGRADEs within that stateid sequence. When a READ, WRITE, or SETATTR which specifies the size attribute, is done, the operation is subject to checking against the access mode to verify that the operation is appropriate given the OPEN with which the operation is associated.

In the case of WRITE-type operations (i.e., WRITEs and SETATTRs which set size), the server must verify that the access mode allows writing and return an NFS4ERR_OPENMODE error if it does not. In the case, of READ, the server may perform the corresponding check on the access mode, or it may choose to allow READ on opens for WRITE only, to accommodate clients whose write implementation may unavoidably do reads (e.g., due to buffer cache constraints). However, even if READs are allowed in these circumstances, the server MUST still check for locks that conflict with the READ (e.g., another open specify denial of READs). Note that a server which does enforce the access mode check on READs need not explicitly check for conflicting share reservations since the existence of OPEN for read access guarantees that no conflicting share reservation can exist.

A stateid of all bits 1 (one) MAY allow READ operations to bypass locking checks at the server. However, WRITE operations with a stateid with bits all 1 (one) MUST NOT bypass locking checks and are treated exactly the same as if a stateid of all bits 0 were used.

A lock may not be granted while a READ or WRITE operation using one of the special stateids is being performed and the range of the lock request conflicts with the range of the READ or WRITE operation. For the purposes of this paragraph, a conflict occurs when a shared lock is requested and a WRITE operation is being performed, or an exclusive lock is requested and either a READ or a WRITE operation is being performed. A SETATTR that sets size is treated similarly to a WRITE as discussed above.

9.1.6. Sequencing of Lock Requests

Locking is different than most NFS operations as it requires "at-most-one" semantics that are not provided by ONCRPC. ONCRPC over a reliable transport is not sufficient because a sequence of locking requests may span multiple TCP connections. In the face of retransmission or reordering, lock or unlock requests must have a well defined and consistent behavior. To accomplish this, each lock request contains a sequence number that is a consecutively increasing integer. Different state-owners have different sequences. The server maintains the last sequence number (L) received and the response that was returned. The server is free to assign any value for the first request issued for any given state-owner.

Note that for requests that contain a sequence number, for each state-owner, there should be no more than one outstanding request.

If a request (r) with a previous sequence number (r < L) is received, it is rejected with the return of error NFS4ERR_BAD_SEQID. Given a properly-functioning client, the response to (r) must have been received before the last request (L) was sent. If a duplicate of last request (r == L) is received, the stored response is returned. If a request beyond the next sequence (r == L + 2) is received, it is rejected with the return of error NFS4ERR_BAD_SEQID. Sequence history is reinitialized whenever the SETCLIENTID/SETCLIENTID_CONFIRM sequence changes the client verifier.

Since the sequence number is represented with an unsigned 32-bit integer, the arithmetic involved with the sequence number is mod 2^32. For an example of modulo arithmetic involving sequence numbers see [33].

It is critical the server maintain the last response sent to the client to provide a more reliable cache of duplicate non-idempotent

requests than that of the traditional cache described in [34]. The traditional duplicate request cache uses a least recently used algorithm for removing unneeded requests. However, the last lock request and response on a given state-owner must be cached as long as the lock state exists on the server.

The client MUST monotonically increment the sequence number for the CLOSE, LOCK, LOCKU, OPEN, OPEN_CONFIRM, and OPEN_DOWNGRADE operations. This is true even in the event that the previous operation that used the sequence number received an error. The only exception to this rule is if the previous operation received one of the following errors: NFS4ERR_STALE_CLIENTID, NFS4ERR_STALE_STATEID, NFS4ERR_BAD_STATEID, NFS4ERR_BAD_SEQID, NFS4ERR_BADXDR, NFS4ERR_RESOURCE, NFS4ERR_NOFILEHANDLE, or NFS4ERR_MOVED.

9.1.7. Recovery from Replayed Requests

As described above, the sequence number is per state-owner. As long as the server maintains the last sequence number received and follows the methods described above, there are no risks of a Byzantine router re-sending old requests. The server need only maintain the (state-owner, sequence number) state as long as there are open files or closed files with locks outstanding.

LOCK, LOCKU, OPEN, OPEN_DOWNGRADE, and CLOSE each contain a sequence number and therefore the risk of the replay of these operations resulting in undesired effects is non-existent while the server maintains the state-owner state.

9.1.8. Interactions of multiple sequence values

Some Operations may have multiple sources of data for request sequence checking and retransmission determination. Some Operations have multiple sequence values associated with multiple types of state-owners. In addition, such Operations may also have a stateid with its own seqid value, that will be checked for validity.

As noted above, there may be multiple sequence values to check. The following rules should be followed by the server in processing these multiple sequence values within a single operation.

- When a sequence value associated with a state-owner is unavailable for checking because the state-owner is unknown to the server, it takes no part in the comparison.

- When any of the state-owner sequence values are invalid, NFS4ERR_BAD_SEQID is returned. When a stateid sequence is checked, NFS4ERR_BAD_STATEID, or NFS4ERR_OLD_STATEID is returned

as appropriate, but NFS4ERR_BAD_SEQID has priority.

- When any one of the sequence values matches a previous request, for a state-owner, it is treated as a retransmission and not re-executed. When the type of the operation does not match that originally used, NFS4ERR_BAD_SEQID is returned. When the server can determine that the request differs from the original it may return NFS4ERR_BAD_SEQID.

- When multiple of the sequence values match previous operations, but the operations are not the same, NFS4ERR_BAD_SEQID is returned.

- When there are no available sequence values available for comparison and the operation is an OPEN, the server indicates to the client that an OPEN_CONFIRM is required, unless it can conclusively determine that confirmation is not required (e.g., by knowing that no open-owner state has ever been released for the current clientid).

9.1.9. Releasing state-owner State

When a particular state-owner no longer holds open or file locking state at the server, the server may choose to release the sequence number state associated with the state-owner. The server may make this choice based on lease expiration, for the reclamation of server memory, or other implementation specific details. Note that when this is done, a retransmitted request, normally identified by a matching state-owner sequence may not be correctly recognized, so that the client will not receive the original response that it would have if the state-owner state was not released.

If the server were able to be sure that a given state-owner would never again be used by a client, such an issue could not arise. Even when the state-owner state is released and the client subsequently uses that state-owner, retransmitted requests will be detected as invalid and the request not executed, although the client may have a recovery path that is more complicated than simply getting the original response back transparently.

In any event, the server is able to safely release state-owner state (in the sense that retransmitted requests will not be erroneously acted upon) when the state-owner no currently being utilized by the client (i.e., there are no open files associated with an open-owner and no lock stateids associated with a lock-owner). The server may choose to hold the state-owner state in order to simplify the recovery path, in the case in which retransmissions of currently active requests are received. However, the period it chooses to hold

this state is implementation specific.

In the case that a LOCK, LOCKU, OPEN_DOWNGRADE, or CLOSE is retransmitted after the server has previously released the state-owner state, the server will find that the state-owner has no files open and an error will be returned to the client. If the state-owner does have a file open, the stateid will not match and again an error is returned to the client.

9.1.10. Use of Open Confirmation

In the case that an OPEN is retransmitted and the open-owner is being used for the first time or the open-owner state has been previously released by the server, the use of the OPEN_CONFIRM operation will prevent incorrect behavior. When the server observes the use of the open-owner for the first time, it will direct the client to perform the OPEN_CONFIRM for the corresponding OPEN. This sequence establishes the use of a open-owner and associated sequence number. Since the OPEN_CONFIRM sequence connects a new open-owner on the server with an existing open-owner on a client, the sequence number may have any value. The OPEN_CONFIRM step assures the server that the value received is the correct one. (see Section 15.20 for further details.)

There are a number of situations in which the requirement to confirm an OPEN would pose difficulties for the client and server, in that they would be prevented from acting in a timely fashion on information received, because that information would be provisional, subject to deletion upon non-confirmation. Fortunately, these are situations in which the server can avoid the need for confirmation when responding to open requests. The two constraints are:

- The server must not bestow a delegation for any open which would require confirmation.

- The server MUST NOT require confirmation on a reclaim-type open (i.e., one specifying claim type CLAIM_PREVIOUS or CLAIM_DELEGATE_PREV).

These constraints are related in that reclaim-type opens are the only ones in which the server may be required to send a delegation. For CLAIM_NULL, sending the delegation is optional while for CLAIM_DELEGATE_CUR, no delegation is sent.

Delegations being sent with an open requiring confirmation are troublesome because recovering from non-confirmation adds undue complexity to the protocol while requiring confirmation on reclaim-type opens poses difficulties in that the inability to resolve the

status of the reclaim until lease expiration may make it difficult to have timely determination of the set of locks being reclaimed (since the grace period may expire).

Requiring open confirmation on reclaim-type opens is avoidable because of the nature of the environments in which such opens are done. For CLAIM_PREVIOUS opens, this is immediately after server reboot, so there should be no time for open-owners to be created, found to be unused, and recycled. For CLAIM_DELEGATE_PREV opens, we are dealing with either a client reboot situation or a network partition resulting in deletion of lease state (and returning NFS4ERR_EXPIRED). A server which supports delegations can be sure that no open-owners for that client have been recycled since client initialization or deletion of lease state and thus can ensure that confirmation will not be required.

9.2. Lock Ranges

The protocol allows a lock owner to request a lock with a byte range and then either upgrade or unlock a sub-range of the initial lock. It is expected that this will be an uncommon type of request. In any case, servers or server filesystems may not be able to support sub-range lock semantics. In the event that a server receives a locking request that represents a sub-range of current locking state for the lock owner, the server is allowed to return the error NFS4ERR_LOCK_RANGE to signify that it does not support sub-range lock operations. Therefore, the client should be prepared to receive this error and, if appropriate, report the error to the requesting application.

The client is discouraged from combining multiple independent locking ranges that happen to be adjacent into a single request since the server may not support sub-range requests and for reasons related to the recovery of file locking state in the event of server failure. As discussed in the Section 9.6.2 below, the server may employ certain optimizations during recovery that work effectively only when the client's behavior during lock recovery is similar to the client's locking behavior prior to server failure.

9.3. Upgrading and Downgrading Locks

If a client has a write lock on a record, it can request an atomic downgrade of the lock to a read lock via the LOCK request, by setting the type to READ_LT. If the server supports atomic downgrade, the request will succeed. If not, it will return NFS4ERR_LOCK_NOTSUPP. The client should be prepared to receive this error, and if appropriate, report the error to the requesting application.

If a client has a read lock on a record, it can request an atomic upgrade of the lock to a write lock via the LOCK request by setting the type to WRITE_LT or WRITEW_LT. If the server does not support atomic upgrade, it will return NFS4ERR_LOCK_NOTSUPP. If the upgrade can be achieved without an existing conflict, the request will succeed. Otherwise, the server will return either NFS4ERR_DENIED or NFS4ERR_DEADLOCK. The error NFS4ERR_DEADLOCK is returned if the client issued the LOCK request with the type set to WRITEW_LT and the server has detected a deadlock. The client should be prepared to receive such errors and if appropriate, report the error to the requesting application.

9.4. Blocking Locks

Some clients require the support of blocking locks. The NFS version 4 protocol must not rely on a callback mechanism and therefore is unable to notify a client when a previously denied lock has been granted. Clients have no choice but to continually poll for the lock. This presents a fairness problem. Two new lock types are added, READW and WRITEW, and are used to indicate to the server that the client is requesting a blocking lock. The server should maintain an ordered list of pending blocking locks. When the conflicting lock is released, the server may wait the lease period for the first waiting client to re-request the lock. After the lease period expires the next waiting client request is allowed the lock. Clients are required to poll at an interval sufficiently small that it is likely to acquire the lock in a timely manner. The server is not required to maintain a list of pending blocked locks as it is used to increase fairness and not correct operation. Because of the unordered nature of crash recovery, storing of lock state to stable storage would be required to guarantee ordered granting of blocking locks.

Servers may also note the lock types and delay returning denial of the request to allow extra time for a conflicting lock to be released, allowing a successful return. In this way, clients can avoid the burden of needlessly frequent polling for blocking locks. The server should take care in the length of delay in the event the client retransmits the request.

If a server receives a blocking lock request, denies it, and then later receives a nonblocking request for the same lock, which is also denied, then it should remove the lock in question from its list of pending blocking locks. Clients should use such a nonblocking request to indicate to the server that this is the last time they intend to poll for the lock, as may happen when the process requesting the lock is interrupted. This is a courtesy to the server, to prevent it from unnecessarily waiting a lease period

before granting other lock requests. However, clients are not required to perform this courtesy, and servers must not depend on them doing so. Also, clients must be prepared for the possibility that this final locking request will be accepted.

9.5. Lease Renewal

The purpose of a lease is to allow a server to remove stale locks that are held by a client that has crashed or is otherwise unreachable. It is not a mechanism for cache consistency and lease renewals may not be denied if the lease interval has not expired.

The client can implicitly provide a positive indication that it is still active and that the associated state held at the server, for the client, is still valid. Any operation made with a valid clientid (DELEGPURGE, LOCK, LOCKT, OPEN, RELEASE_LOCKOWNER, or RENEW) or a valid stateid (CLOSE, DELEGRETURN, LOCK, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, SETATTR, or WRITE) informs the server to renew all of the leases for that client (i.e., all those sharing a given client ID). In the latter case, the stateid must not be one of the special stateids consisting of all bits 0 or all bits 1.

Note that if the client had restarted or rebooted, the client would not be making these requests without issuing the SETCLIENTID/ SETCLIENTID_CONFIRM sequence. The use of the SETCLIENTID/ SETCLIENTID_CONFIRM sequence (one that changes the client verifier) notifies the server to drop the locking state associated with the client. SETCLIENTID/SETCLIENTID_CONFIRM never renews a lease.

If the server has rebooted, the stateids (NFS4ERR_STALE_STATEID error) or the client ID (NFS4ERR_STALE_CLIENTID error) will not be valid hence preventing spurious renewals.

This approach allows for low overhead lease renewal which scales well. In the typical case no extra RPC calls are required for lease renewal and in the worst case one RPC is required every lease period (i.e., a RENEW operation). The number of locks held by the client is not a factor since all state for the client is involved with the lease renewal action.

Since all operations that create a new lease also renew existing leases, the server must maintain a common lease expiration time for all valid leases for a given client. This lease time can then be easily updated upon implicit lease renewal actions.

9.6. Crash Recovery

The important requirement in crash recovery is that both the client and the server know when the other has failed. Additionally, it is required that a client sees a consistent view of data across server restarts or reboots. All READ and WRITE operations that may have been queued within the client or network buffers must wait until the client has successfully recovered the locks protecting the READ and WRITE operations.

9.6.1. Client Failure and Recovery

In the event that a client fails, the server may recover the client's locks when the associated leases have expired. Conflicting locks from another client may only be granted after this lease expiration. If the client is able to restart or reinitialize within the lease period the client may be forced to wait the remainder of the lease period before obtaining new locks.

To minimize client delay upon restart, open and lock requests are associated with an instance of the client by a client supplied verifier. This verifier is part of the initial SETCLIENTID call made by the client. The server returns a client ID as a result of the SETCLIENTID operation. The client then confirms the use of the client ID with SETCLIENTID_CONFIRM. The client ID in combination with an opaque owner field is then used by the client to identify the open owner for OPEN. This chain of associations is then used to identify all locks for a particular client.

Since the verifier will be changed by the client upon each initialization, the server can compare a new verifier to the verifier associated with currently held locks and determine that they do not match. This signifies the client's new instantiation and subsequent loss of locking state. As a result, the server is free to release all locks held which are associated with the old client ID which was derived from the old verifier.

Note that the verifier must have the same uniqueness properties of the verifier for the COMMIT operation.

9.6.2. Server Failure and Recovery

If the server loses locking state (usually as a result of a restart or reboot), it must allow clients time to discover this fact and re-establish the lost locking state. The client must be able to re-establish the locking state without having the server deny valid requests because the server has granted conflicting access to another client. Likewise, if there is the possibility that clients have not

yet re-established their locking state for a file, the server must disallow READ and WRITE operations for that file. The duration of this recovery period is equal to the duration of the lease period.

A client can determine that server failure (and thus loss of locking state) has occurred, when it receives one of two errors. The NFS4ERR_STALE_STATEID error indicates a stateid invalidated by a reboot or restart. The NFS4ERR_STALE_CLIENTID error indicates a client ID invalidated by reboot or restart. When either of these are received, the client must establish a new client ID (see Section 9.1.1) and re-establish the locking state as discussed below.

The period of special handling of locking and READs and WRITEs, equal in duration to the lease period, is referred to as the "grace period". During the grace period, clients recover locks and the associated state by reclaim-type locking requests (i.e., LOCK requests with reclaim set to true and OPEN operations with a claim type of either CLAIM_PREVIOUS or CLAIM_DELEGATE_PREV). During the grace period, the server must reject READ and WRITE operations and non-reclaim locking requests (i.e., other LOCK and OPEN operations) with an error of NFS4ERR_GRACE.

If the server can reliably determine that granting a non-reclaim request will not conflict with reclamation of locks by other clients, the NFS4ERR_GRACE error does not have to be returned and the non-reclaim client request can be serviced. For the server to be able to service READ and WRITE operations during the grace period, it must again be able to guarantee that no possible conflict could arise between an impending reclaim locking request and the READ or WRITE operation. If the server is unable to offer that guarantee, the NFS4ERR_GRACE error must be returned to the client.

For a server to provide simple, valid handling during the grace period, the easiest method is to simply reject all non-reclaim locking requests and READ and WRITE operations by returning the NFS4ERR_GRACE error. However, a server may keep information about granted locks in stable storage. With this information, the server could determine if a regular lock or READ or WRITE operation can be safely processed.

For example, if a count of locks on a given file is available in stable storage, the server can track reclaimed locks for the file and when all reclaims have been processed, non-reclaim locking requests may be processed. This way the server can ensure that non-reclaim locking requests will not conflict with potential reclaim requests. With respect to I/O requests, if the server is able to determine that there are no outstanding reclaim requests for a file by information from stable storage or another similar mechanism, the processing of

I/O requests could proceed normally for the file.

To reiterate, for a server that allows non-reclaim lock and I/O requests to be processed during the grace period, it MUST determine that no lock subsequently reclaimed will be rejected and that no lock subsequently reclaimed would have prevented any I/O operation processed during the grace period.

Clients should be prepared for the return of NFS4ERR_GRACE errors for non-reclaim lock and I/O requests. In this case the client should employ a retry mechanism for the request. A delay (on the order of several seconds) between retries should be used to avoid overwhelming the server. Further discussion of the general issue is included in [21]. The client must account for the server that is able to perform I/O and non-reclaim locking requests within the grace period as well as those that cannot do so.

A reclaim-type locking request outside the server's grace period can only succeed if the server can guarantee that no conflicting lock or I/O request has been granted since reboot or restart.

A server may, upon restart, establish a new value for the lease period. Therefore, clients should, once a new client ID is established, refetch the lease_time attribute and use it as the basis for lease renewal for the lease associated with that server. However, the server must establish, for this restart event, a grace period at least as long as the lease period for the previous server instantiation. This allows the client state obtained during the previous server instance to be reliably re-established.

9.6.3. Network Partitions and Recovery

If the duration of a network partition is greater than the lease period provided by the server, the server will have not received a lease renewal from the client. If this occurs, the server may cancel the lease and free all locks held for the client. As a result, all stateids held by the client will become invalid or stale. Once the client is able to reach the server after such a network partition, all I/O submitted by the client with the now invalid stateids will fail with the server returning the error NFS4ERR_EXPIRED. Once this error is received, the client will suitably notify the application that held the lock.

9.6.3.1. Courtesy Locks

As a courtesy to the client or as an optimization, the server may continue to hold locks, including delegations, on behalf of a client for which recent communication has extended beyond the lease period,

delaying the cancellation of the lease. If the server receives a lock or I/O request that conflicts with one of these courtesy locks or if it runs out of resources, the server MAY cause lease cancellation to occur at that time and henceforth return NFS4ERR_EXPIRED when any of the stateids associated with the freed locks is used. If lease cancellation has not occurred and the server receives a lock or I/O request that conflicts with one of the courtesy locks, the requirements are as follows:

- In the case of a courtesy lock which is not a delegation, it MUST free the courtesy lock and grant the new request.

- In the case of lock or IO request which conflicts with a delegation which is being held as courtesy lock, the server MAY delay resolution of request but MUST NOT reject the request and MUST free the delegation and grant the new request eventually.

- In the case of a requests for a delegation which conflicts with a delegation which is being held as courtesy lock, the server MAY grant the new request or not as it chooses, but if it grants the conflicting request, the delegation haled as courtesy lock MUST be freed.

If the server does not reboot or cancel the lease before the network partition is healed, when the original client tries to access a courtesy lock which was freed, the server SHOULD send back a NFS4ERR_BAD_STATEID to the client. If the client tries to access a courtesy lock which was not freed, then the server SHOULD mark all of the courtesy locks as implicitly being renewed.

9.6.3.2. Lease Cancellation

As a result of lease expiration, leases may be cancelled, either immediately upon expiration or subsequently, depending on the occurrence of a conflicting lock or extension of the period of partition beyond what the server will tolerate.

When a lease is cancelled, all locking state associated with it is freed and use of any the associated stateids will result in NFS4ERR_EXPIRED being returned. Similarly, use of the associated clientid will result in NFS4ERR_EXPIRED being returned.

The client should recover from this situation by using SETCLIENTID followed by SETCLIENTID_CONFIRM, in order to establish a new clientid. Once a lock is obtained using this clientid, a lease will be established.

9.6.3.3. Client's Reaction to a Freed Lock

There is no way for a client to predetermine how a given server is going to behave during a network partition. When the partition heals, either the client still has all of its locks, it has some of its locks, or it has none of them. The client will be able to examine the various error return values to determine its response.

NFS4ERR_EXPIRED:

All locks have been freed as a result of a lease cancellation which occurred during the partition. The client should use a SETCLIENTID to recover.

NFS4ERR_ADMIN_REVOKED:

The current lock has been revoked before, during, or after the partition. The client SHOULD handle this error as it normally would.

NFS4ERR_BAD_STATEID:

The current lock has been revoked/released during the partition and the server did not reboot. Other locks MAY still be renewed. The client need not do a SETCLIENTID and instead SHOULD probe via a RENEW call.

NFS4ERR_RECLAIM_BAD:

The current lock has been revoked during the partition and the server rebooted. The server might have no information on the other locks. They may still be renewable.

NFS4ERR_NO_GRACE:

The client's locks have been revoked during the partition and the server rebooted. None of the client's locks will be renewable.

NFS4ERR_OLD_STATEID:

The server has not rebooted. The client SHOULD handle this error as it normally would.

9.6.3.4. Edge Conditions

When a network partition is combined with a server reboot, then both the server and client have responsibilities to ensure that the client does not reclaim a lock which it should no longer be able to access.

Briefly those are:

- Client's responsibility: A client MUST NOT attempt to reclaim any locks which it did not hold at the end of its most recent successfully established client lease.

- Server's responsibility: A server MUST NOT allow a client to reclaim a lock unless it knows that it could not have since granted a conflicting lock. However, in deciding whether a conflicting lock could have been granted, it is permitted to assume its clients are responsible, as above.

A server may consider a client's lease "successfully established" once it has received an open operation from that client.

The above are directed to CLAIM_PREVIOUS reclaims and not to CLAIM_DELEGATE_PREV reclaims, which generally do not involve a server reboot. However, when a server persistently stores delegation information to support CLAIM_DELEGATE_PREV across a period in which both client and server are down at the same time, similar strictures apply.

The next sections give examples showing what can go wrong if these responsibilities are neglected, and provides examples of server implementation strategies that could meet a server's responsibilities.

9.6.3.4.1. First Server Edge Condition

The first edge condition has the following scenario:

1. Client A acquires a lock.

2. Client A and server experience mutual network partition, such that client A is unable to renew its lease.

3. Client A's lease expires, so server releases lock.

4. Client B acquires a lock that would have conflicted with that of Client A.

5. Client B releases the lock

6. Server reboots

7. Network partition between client A and server heals.

8. Client A issues a RENEW operation, and gets back a NFS4ERR_STALE_CLIENTID.

9. Client A reclaims its lock within the server's grace period.

Thus, at the final step, the server has erroneously granted client A's lock reclaim. If client B modified the object the lock was protecting, client A will experience object corruption.

9.6.3.4.2. Second Server Edge Condition

The second known edge condition follows:

1. Client A acquires a lock.

2. Server reboots.

3. Client A and server experience mutual network partition, such that client A is unable to reclaim its lock within the grace period.

4. Server's reclaim grace period ends. Client A has no locks recorded on server.

5. Client B acquires a lock that would have conflicted with that of Client A.

6. Client B releases the lock.

7. Server reboots a second time.

8. Network partition between client A and server heals.

9. Client A issues a RENEW operation, and gets back a NFS4ERR_STALE_CLIENTID.

10. Client A reclaims its lock within the server's grace period.

As with the first edge condition, the final step of the scenario of the second edge condition has the server erroneously granting client A's lock reclaim.

9.6.3.4.3. Handling Server Edge Conditions

In both of the above examples, the client attempts reclaim of a lock that it held at the end of its most recent successfully established lease; thus, it has fulfilled its responsibility.

The server, however, has failed, by granting a reclaim, despite having granted a conflicting lock since the reclaimed lock was last held.

Solving these edge conditions requires that the server either assume after it reboots that edge condition occurs, and thus return NFS4ERR_NO_GRACE for all reclaim attempts, or that the server record some information in stable storage. The amount of information the server records in stable storage is in inverse proportion to how harsh the server wants to be whenever the edge conditions occur. The server that is completely tolerant of all edge conditions will record in stable storage every lock that is acquired, removing the lock record from stable storage only when the lock is unlocked by the client and the lock's owner advances the sequence number such that the lock release is not the last stateful event for the owner's sequence. For the two aforementioned edge conditions, the harshest a server can be, and still support a grace period for reclaims, requires that the server record in stable storage information some minimal information. For example, a server implementation could, for each client, save in stable storage a record containing:

- the client's id string
- a boolean that indicates if the client's lease expired or if there was administrative intervention (see Section 9.8) to revoke a byte-range lock, share reservation, or delegation
- a timestamp that is updated the first time after a server boot or reboot the client acquires byte-range locking, share reservation, or delegation state on the server. The timestamp need not be updated on subsequent lock requests until the server reboots.

The server implementation would also record in the stable storage the timestamps from the two most recent server reboots.

Assuming the above record keeping, for the first edge condition, after the server reboots, the record that client A's lease expired means that another client could have acquired a conflicting record lock, share reservation, or delegation. Hence the server must reject a reclaim from client A with the error NFS4ERR_NO_GRACE or NFS4ERR_RECLAIM_BAD.

For the second edge condition, after the server reboots for a second time, the record that the client had an unexpired record lock, share reservation, or delegation established before the server's previous incarnation means that the server must reject a reclaim from client A with the error NFS4ERR_NO_GRACE or NFS4ERR_RECLAIM_BAD.

Regardless of the level and approach to record keeping, the server MUST implement one of the following strategies (which apply to reclaims of share reservations, byte-range locks, and delegations):

1. Reject all reclaims with NFS4ERR_NO_GRACE. This is super harsh, but necessary if the server does not want to record lock state in stable storage.

2. Record sufficient state in stable storage to meet its responsibilities. In doubt, the server should err on the side of being harsh.

   In the event that, after a server reboot, the server determines that there is unrecoverable damage or corruption to the the stable storage, then for all clients and/or locks affected, the server MUST return NFS4ERR_NO_GRACE.

9.6.3.4.4. Client Edge Condition

A third edge condition effects the client and not the server. If the server reboots in the middle of the client reclaiming some locks and then a network partition is established, the client might be in the situation of having reclaimed some, but not all locks. In that case, a conservative client would assume that the non-reclaimed locks were revoked.

The third known edge condition follows:

1. Client A acquires a lock 1.

2. Client A acquires a lock 2.

3. Server reboots.

4. Client A issues a RENEW operation, and gets back a NFS4ERR_STALE_CLIENTID.

5. Client A reclaims its lock 1 within the server's grace period.

6. Client A and server experience mutual network partition, such that client A is unable to reclaim its remaining locks within the grace period.

7. Server's reclaim grace period ends.

8. Client B acquires a lock that would have conflicted with Client A's lock 2.

9. Client B releases the lock.

10. Server reboots a second time.

11. Network partition between client A and server heals.

12. Client A issues a RENEW operation, and gets back a NFS4ERR_STALE_CLIENTID.

13. Client A reclaims both lock 1 and lock 2 within the server's grace period.

At the last step, the client reclaims lock 2 as if it had held that lock continuously, when in fact a conflicting lock was granted to client B.

This occurs because the client failed its responsibility, by attempting to reclaim lock 2 even though it had not held that lock at the end of the lease that was established by the SETCLIENTID after the first server reboot. (The client did hold lock 2 on a previous lease. But it is only the most recent lease that matters.)

A server could avoid this situation by rejecting the reclaim of lock 2. However, to do so accurately it would have to ensure that additional information about individual locks held survives reboot. Server implementations are not required to do that, so the client must not assume that the server will.

Instead, a client MUST reclaim only those locks which it successfully acquired from the previous server instance, omitting any that it failed to reclaim before a new reboot. Thus, in the last step above, client A should reclaim only lock 1.

9.6.3.4.5. Client's Handling of Reclaim Errors

A mandate for the client's handling of the NFS4ERR_NO_GRACE and NFS4ERR_RECLAIM_BAD errors is outside the scope of this specification, since the strategies for such handling are very dependent on the client's operating environment. However, one potential approach is described below.

When the client's reclaim fails, it could examine the change attribute of the objects the client is trying to reclaim state for, and use that to determine whether to re-establish the state via normal OPEN or LOCK requests. This is acceptable provided the client's operating environment allows it. In other words, the client implementor is advised to document for his users the behavior. The client could also inform the application that its byte-range lock or

share reservations (whether they were delegated or not) have been lost, such as via a UNIX signal, a GUI pop-up window, etc. See Section 10.5, for a discussion of what the client should do for dealing with unreclaimed delegations on client state.

For further discussion of revocation of locks see Section 9.8.

9.7. Recovery from a Lock Request Timeout or Abort

In the event a lock request times out, a client may decide to not retry the request. The client may also abort the request when the process for which it was issued is terminated (e.g., in UNIX due to a signal). It is possible though that the server received the request and acted upon it. This would change the state on the server without the client being aware of the change. It is paramount that the client re-synchronize state with server before it attempts any other operation that takes a seqid and/or a stateid with the same state-owner. This is straightforward to do without a special re-synchronize operation.

Since the server maintains the last lock request and response received on the state-owner, for each state-owner, the client should cache the last lock request it sent such that the lock request did not receive a response. From this, the next time the client does a lock operation for the state-owner, it can send the cached request, if there is one, and if the request was one that established state (e.g., a LOCK or OPEN operation), the server will return the cached result or if never saw the request, perform it. The client can follow up with a request to remove the state (e.g., a LOCKU or CLOSE operation). With this approach, the sequencing and stateid information on the client and server for the given state-owner will re-synchronize and in turn the lock state will re-synchronize.

9.8. Server Revocation of Locks

At any point, the server can revoke locks held by a client and the client must be prepared for this event. When the client detects that its locks have been or may have been revoked, the client is responsible for validating the state information between itself and the server. Validating locking state for the client means that it must verify or reclaim state for each lock currently held.

The first instance of lock revocation is upon server reboot or re-initialization. In this instance the client will receive an error (NFS4ERR_STALE_STATEID or NFS4ERR_STALE_CLIENTID) and the client will proceed with normal crash recovery as described in the previous section.

The second lock revocation event is the inability to renew the lease before expiration. While this is considered a rare or unusual event, the client must be prepared to recover. Both the server and client will be able to detect the failure to renew the lease and are capable of recovering without data corruption. For the server, it tracks the last renewal event serviced for the client and knows when the lease will expire. Similarly, the client must track operations which will renew the lease period. Using the time that each such request was sent and the time that the corresponding reply was received, the client should bound the time that the corresponding renewal could have occurred on the server and thus determine if it is possible that a lease period expiration could have occurred.

The third lock revocation event can occur as a result of administrative intervention within the lease period. While this is considered a rare event, it is possible that the server's administrator has decided to release or revoke a particular lock held by the client. As a result of revocation, the client will receive an error of NFS4ERR_ADMIN_REVOKED. In this instance the client may assume that only the state-owner's locks have been lost. The client notifies the lock holder appropriately. The client may not assume the lease period has been renewed as a result of a failed operation.

When the client determines the lease period may have expired, the client must mark all locks held for the associated lease as "unvalidated". This means the client has been unable to re-establish or confirm the appropriate lock state with the server. As described in Section 9.6, there are scenarios in which the server may grant conflicting locks after the lease period has expired for a client. When it is possible that the lease period has expired, the client must validate each lock currently held to ensure that a conflicting lock has not been granted. The client may accomplish this task by issuing an I/O request, either a pending I/O or a zero-length read, specifying the stateid associated with the lock in question. If the response to the request is success, the client has validated all of the locks governed by that stateid and re-established the appropriate state between itself and the server.

If the I/O request is not successful, then one or more of the locks associated with the stateid was revoked by the server and the client must notify the owner.

9.9. Share Reservations

A share reservation is a mechanism to control access to a file. It is a separate and independent mechanism from byte-range locking. When a client opens a file, it issues an OPEN operation to the server specifying the type of access required (READ, WRITE, or BOTH) and the

type of access to deny others (OPEN4_SHARE_DENY_NONE, OPEN4_SHARE_DENY_READ, OPEN4_SHARE_DENY_WRITE, or OPEN4_SHARE_DENY_BOTH). If the OPEN fails the client will fail the application's open request.

Pseudo-code definition of the semantics:

```
  if (request.access == 0)
          return (NFS4ERR_INVAL)
  else if ((request.access & file_state.deny)) ||
      (request.deny & file_state.access))
          return (NFS4ERR_DENIED)
```

This checking of share reservations on OPEN is done with no exception for an existing OPEN for the same open-owner.

The constants used for the OPEN and OPEN_DOWNGRADE operations for the access and deny fields are as follows:

```
const OPEN4_SHARE_ACCESS_READ   = 0x00000001;
const OPEN4_SHARE_ACCESS_WRITE  = 0x00000002;
const OPEN4_SHARE_ACCESS_BOTH   = 0x00000003;

const OPEN4_SHARE_DENY_NONE     = 0x00000000;
const OPEN4_SHARE_DENY_READ     = 0x00000001;
const OPEN4_SHARE_DENY_WRITE    = 0x00000002;
const OPEN4_SHARE_DENY_BOTH     = 0x00000003;
```

9.10. OPEN/CLOSE Operations

To provide correct share semantics, a client MUST use the OPEN operation to obtain the initial filehandle and indicate the desired access and what access, if any, to deny. Even if the client intends to use a stateid of all 0's or all 1's, it must still obtain the filehandle for the regular file with the OPEN operation so the appropriate share semantics can be applied. Clients that do not have a deny mode built into their programming interfaces for opening a file should request a deny mode of OPEN4_SHARE_DENY_NONE.

The OPEN operation with the CREATE flag, also subsumes the CREATE operation for regular files as used in previous versions of the NFS protocol. This allows a create with a share to be done atomically.

The CLOSE operation removes all share reservations held by the open-owner on that file. If byte-range locks are held, the client SHOULD release all locks before issuing a CLOSE. The server MAY free all outstanding locks on CLOSE but some servers may not support the CLOSE of a file that still has byte-range locks held. The server MUST

return failure, NFS4ERR_LOCKS_HELD, if any locks would exist after the CLOSE.

The LOOKUP operation will return a filehandle without establishing any lock state on the server. Without a valid stateid, the server will assume the client has the least access. For example, if one client opened a file with OPEN4_SHARE_DENY_BOTH and another client accesses the file via a filehandle obtained through LOOKUP, the second client could only read the file using the special read bypass stateid. The second client could not WRITE the file at all because it would not have a valid stateid from OPEN and the special anonymous stateid would not be allowed access.

9.10.1. Close and Retention of State Information

Since a CLOSE operation requests deallocation of a stateid, dealing with retransmission of the CLOSE, may pose special difficulties, since the state information, which normally would be used to determine the state of the open file being designated, might be deallocated, resulting in an NFS4ERR_BAD_STATEID error.

Servers may deal with this problem in a number of ways. To provide the greatest degree assurance that the protocol is being used properly, a server should, rather than deallocate the stateid, mark it as close-pending, and retain the stateid with this status, until later deallocation. In this way, a retransmitted CLOSE can be recognized since the stateid points to state information with this distinctive status, so that it can be handled without error.

When adopting this strategy, a server should retain the state information until the earliest of:

- Another validly sequenced request for the same open-owner, that is not a retransmission.

- The time that an open-owner is freed by the server due to period with no activity.

- All locks for the client are freed as a result of a SETCLIENTID.

Servers may avoid this complexity, at the cost of less complete protocol error checking, by simply responding NFS4_OK in the event of a CLOSE for a deallocated stateid, on the assumption that this case must be caused by a retransmitted close. When adopting this approach, it is desirable to at least log an error when returning a no-error indication in this situation. If the server maintains a reply-cache mechanism, it can verify the CLOSE is indeed a retransmission and avoid error logging in most cases.

9.11. Open Upgrade and Downgrade

When an OPEN is done for a file and the open-owner for which the open is being done already has the file open, the result is to upgrade the open file status maintained on the server to include the access and deny bits specified by the new OPEN as well as those for the existing OPEN. The result is that there is one open file, as far as the protocol is concerned, and it includes the union of the access and deny bits for all of the OPEN requests completed. Only a single CLOSE will be done to reset the effects of both OPENs. Note that the client, when issuing the OPEN, may not know that the same file is in fact being opened. The above only applies if both OPENs result in the OPENed object being designated by the same filehandle.

When the server chooses to export multiple filehandles corresponding to the same file object and returns different filehandles on two different OPENs of the same file object, the server MUST NOT "OR" together the access and deny bits and coalesce the two open files. Instead the server must maintain separate OPENs with separate stateids and will require separate CLOSEs to free them.

When multiple open files on the client are merged into a single open file object on the server, the close of one of the open files (on the client) may necessitate change of the access and deny status of the open file on the server. This is because the union of the access and deny bits for the remaining opens may be smaller (i.e., a proper subset) than previously. The OPEN_DOWNGRADE operation is used to make the necessary change and the client should use it to update the server so that share reservation requests by other clients are handled properly. The stateid returned has the same "other" field as that passed to the server. The "seqid" value in the returned stateid MUST be incremented, even in situations in which there is no change to the access and deny bits for the file.

9.12. Short and Long Leases

When determining the time period for the server lease, the usual lease tradeoffs apply. Short leases are good for fast server recovery at a cost of increased RENEW or READ (with zero length) requests. Longer leases are certainly kinder and gentler to servers trying to handle very large numbers of clients. The number of RENEW requests drop in proportion to the lease time. The disadvantages of long leases are slower recovery after server failure (the server must wait for the leases to expire and the grace period to elapse before granting new lock requests) and increased file contention (if client fails to transmit an unlock request then server must wait for lease expiration before granting new locks).

Long leases are usable if the server is able to store lease state in non-volatile memory. Upon recovery, the server can reconstruct the lease state from its non-volatile memory and continue operation with its clients and therefore long leases would not be an issue.

9.13. Clocks, Propagation Delay, and Calculating Lease Expiration

To avoid the need for synchronized clocks, lease times are granted by the server as a time delta. However, there is a requirement that the client and server clocks do not drift excessively over the duration of the lock. There is also the issue of propagation delay across the network which could easily be several hundred milliseconds as well as the possibility that requests will be lost and need to be retransmitted.

To take propagation delay into account, the client should subtract it from lease times (e.g., if the client estimates the one-way propagation delay as 200 msec, then it can assume that the lease is already 200 msec old when it gets it). In addition, it will take another 200 msec to get a response back to the server. So the client must send a lock renewal or write data back to the server 400 msec before the lease would expire.

The server's lease period configuration should take into account the network distance of the clients that will be accessing the server's resources. It is expected that the lease period will take into account the network propagation delays and other network delay factors for the client population. Since the protocol does not allow for an automatic method to determine an appropriate lease period, the server's administrator may have to tune the lease period.

9.14. Migration, Replication and State

When responsibility for handling a given file system is transferred to a new server (migration) or the client chooses to use an alternate server (e.g., in response to server unresponsiveness) in the context of file system replication, the appropriate handling of state shared between the client and server (i.e., locks, leases, stateids, and client IDs) is as described below. The handling differs between migration and replication. For related discussion of file server state and recover of such see the sections under Section 9.6.

If a server replica or a server immigrating a filesystem agrees to, or is expected to, accept opaque values from the client that originated from another server, then it is a wise implementation practice for the servers to encode the "opaque" values in network byte order. This way, servers acting as replicas or immigrating filesystems will be able to parse values like stateids, directory

cookies, filehandles, etc. even if their native byte order is different from other servers cooperating in the replication and migration of the filesystem.

9.14.1. Migration and State

In the case of migration, the servers involved in the migration of a filesystem SHOULD transfer all server state from the original to the new server. This must be done in a way that is transparent to the client. This state transfer will ease the client's transition when a filesystem migration occurs. If the servers are successful in transferring all state, the client will continue to use stateids assigned by the original server. Therefore the new server must recognize these stateids as valid. This holds true for the client ID as well. Since responsibility for an entire filesystem is transferred with a migration event, there is no possibility that conflicts will arise on the new server as a result of the transfer of locks.

As part of the transfer of information between servers, leases would be transferred as well. The leases being transferred to the new server will typically have a different expiration time from those for the same client, previously on the old server. To maintain the property that all leases on a given server for a given client expire at the same time, the server should advance the expiration time to the later of the leases being transferred or the leases already present. This allows the client to maintain lease renewal of both classes without special effort.

The servers may choose not to transfer the state information upon migration. However, this choice is discouraged. In this case, when the client presents state information from the original server (e.g., in a RENEW op or a READ op of zero length), the client must be prepared to receive either NFS4ERR_STALE_CLIENTID or NFS4ERR_STALE_STATEID from the new server. The client should then recover its state information as it normally would in response to a server failure. The new server must take care to allow for the recovery of state information as it would in the event of server restart.

A client SHOULD re-establish new callback information with the new server as soon as possible, according to sequences described in Section 15.35 and Section 15.36. This ensures that server operations are not blocked by the inability to recall delegations.

9.14.2. Replication and State

Since client switch-over in the case of replication is not under server control, the handling of state is different. In this case, leases, stateids and client IDs do not have validity across a transition from one server to another. The client must re-establish its locks on the new server. This can be compared to the re-establishment of locks by means of reclaim-type requests after a server reboot. The difference is that the server has no provision to distinguish requests reclaiming locks from those obtaining new locks or to defer the latter. Thus, a client re-establishing a lock on the new server (by means of a LOCK or OPEN request), may have the requests denied due to a conflicting lock. Since replication is intended for read-only use of filesystems, such denial of locks should not pose large difficulties in practice. When an attempt to re-establish a lock on a new server is denied, the client should treat the situation as if his original lock had been revoked.

9.14.3. Notification of Migrated Lease

In the case of lease renewal, the client may not be submitting requests for a filesystem that has been migrated to another server. This can occur because of the implicit lease renewal mechanism. The client renews leases for all filesystems when submitting a request to any one filesystem at the server.

In order for the client to schedule renewal of leases that may have been relocated to the new server, the client must find out about lease relocation before those leases expire. To accomplish this, all operations which implicitly renew leases for a client (such as OPEN, CLOSE, READ, WRITE, RENEW, LOCK, and others), will return the error NFS4ERR_LEASE_MOVED if responsibility for any of the leases to be renewed has been transferred to a new server. This condition will continue until the client receives an NFS4ERR_MOVED error and the server receives the subsequent GETATTR(fs_locations) for an access to each filesystem for which a lease has been moved to a new server. By convention, the compound including the GETATTR(fs_locations) SHOULD append a RENEW operation to permit the server to identify the client doing the access.

Upon receiving the NFS4ERR_LEASE_MOVED error, a client that supports filesystem migration MUST probe all filesystems from that server on which it holds open state. Once the client has successfully probed all those filesystems which are migrated, the server MUST resume normal handling of stateful requests from that client.

In order to support legacy clients that do not handle the NFS4ERR_LEASE_MOVED error correctly, the server SHOULD time out after

a wait of at least two lease periods, at which time it will resume normal handling of stateful requests from all clients. If a client attempts to access the migrated files, the server MUST reply NFS4ERR_MOVED.

When the client receives an NFS4ERR_MOVED error, the client can follow the normal process to obtain the new server information (through the fs_locations attribute) and perform renewal of those leases on the new server. If the server has not had state transferred to it transparently, the client will receive either NFS4ERR_STALE_CLIENTID or NFS4ERR_STALE_STATEID from the new server, as described above. The client can then recover state information as it does in the event of server failure.

9.14.4. Migration and the Lease_time Attribute

In order that the client may appropriately manage its leases in the case of migration, the destination server must establish proper values for the lease_time attribute.

When state is transferred transparently, that state should include the correct value of the lease_time attribute. The lease_time attribute on the destination server must never be less than that on the source since this would result in premature expiration of leases granted by the source server. Upon migration in which state is transferred transparently, the client is under no obligation to re-fetch the lease_time attribute and may continue to use the value previously fetched (on the source server).

If state has not been transferred transparently (i.e., the client sees a real or simulated server reboot), the client should fetch the value of lease_time on the new (i.e., destination) server, and use it for subsequent locking requests. However the server must respect a grace period at least as long as the lease_time on the source server, in order to ensure that clients have ample time to reclaim their locks before potentially conflicting non-reclaimed locks are granted. The means by which the new server obtains the value of lease_time on the old server is left to the server implementations. It is not specified by the NFS version 4 protocol.

10. Client-Side Caching

Client-side caching of data, of file attributes, and of file names is essential to providing good performance with the NFS protocol. Providing distributed cache coherence is a difficult problem and previous versions of the NFS protocol have not attempted it. Instead, several NFS client implementation techniques have been used

to reduce the problems that a lack of coherence poses for users. These techniques have not been clearly defined by earlier protocol specifications and it is often unclear what is valid or invalid client behavior.

The NFSv4 protocol uses many techniques similar to those that have been used in previous protocol versions. The NFSv4 protocol does not provide distributed cache coherence. However, it defines a more limited set of caching guarantees to allow locks and share reservations to be used without destructive interference from client side caching.

In addition, the NFSv4 protocol introduces a delegation mechanism which allows many decisions normally made by the server to be made locally by clients. This mechanism provides efficient support of the common cases where sharing is infrequent or where sharing is read-only.

10.1. Performance Challenges for Client-Side Caching

Caching techniques used in previous versions of the NFS protocol have been successful in providing good performance. However, several scalability challenges can arise when those techniques are used with very large numbers of clients. This is particularly true when clients are geographically distributed which classically increases the latency for cache re-validation requests.

The previous versions of the NFS protocol repeat their file data cache validation requests at the time the file is opened. This behavior can have serious performance drawbacks. A common case is one in which a file is only accessed by a single client. Therefore, sharing is infrequent.

In this case, repeated reference to the server to find that no conflicts exist is expensive. A better option with regards to performance is to allow a client that repeatedly opens a file to do so without reference to the server. This is done until potentially conflicting operations from another client actually occur.

A similar situation arises in connection with file locking. Sending file lock and unlock requests to the server as well as the read and write requests necessary to make data caching consistent with the locking semantics (see Section 10.3.2) can severely limit performance. When locking is used to provide protection against infrequent conflicts, a large penalty is incurred. This penalty may discourage the use of file locking by applications.

The NFSv4 protocol provides more aggressive caching strategies with

the following design goals:

- Compatibility with a large range of server semantics.
- Provide the same caching benefits as previous versions of the NFS protocol when unable to provide the more aggressive model.
- Requirements for aggressive caching are organized so that a large portion of the benefit can be obtained even when not all of the requirements can be met.

The appropriate requirements for the server are discussed in later sections in which specific forms of caching are covered (see Section 10.4).

10.2. Delegation and Callbacks

Recallable delegation of server responsibilities for a file to a client improves performance by avoiding repeated requests to the server in the absence of inter-client conflict. With the use of a "callback" RPC from server to client, a server recalls delegated responsibilities when another client engages in sharing of a delegated file.

A delegation is passed from the server to the client, specifying the object of the delegation and the type of delegation. There are different types of delegations but each type contains a stateid to be used to represent the delegation when performing operations that depend on the delegation. This stateid is similar to those associated with locks and share reservations but differs in that the stateid for a delegation is associated with a client ID and may be used on behalf of all the open-owners for the given client. A delegation is made to the client as a whole and not to any specific process or thread of control within it.

Because callback RPCs may not work in all environments (due to firewalls, for example), correct protocol operation does not depend on them. Preliminary testing of callback functionality by means of a CB_NULL procedure determines whether callbacks can be supported. The CB_NULL procedure checks the continuity of the callback path. A server makes a preliminary assessment of callback availability to a given client and avoids delegating responsibilities until it has determined that callbacks are supported. Because the granting of a delegation is always conditional upon the absence of conflicting access, clients must not assume that a delegation will be granted and they must always be prepared for OPENs to be processed without any delegations being granted.

Once granted, a delegation behaves in most ways like a lock. There is an associated lease that is subject to renewal together with all of the other leases held by that client.

Unlike locks, an operation by a second client to a delegated file will cause the server to recall a delegation through a callback.

On recall, the client holding the delegation must flush modified state (such as modified data) to the server and return the delegation. The conflicting request will not be acted on until the recall is complete. The recall is considered complete when the client returns the delegation or the server times its wait for the delegation to be returned and revokes the delegation as a result of the timeout. In the interim, the server will either delay responding to conflicting requests or respond to them with NFS4ERR_DELAY. Following the resolution of the recall, the server has the information necessary to grant or deny the second client's request.

At the time the client receives a delegation recall, it may have substantial state that needs to be flushed to the server. Therefore, the server should allow sufficient time for the delegation to be returned since it may involve numerous RPCs to the server. If the server is able to determine that the client is diligently flushing state to the server as a result of the recall, the server may extend the usual time allowed for a recall. However, the time allowed for recall completion should not be unbounded.

An example of this is when responsibility to mediate opens on a given file is delegated to a client (see Section 10.4). The server will not know what opens are in effect on the client. Without this knowledge the server will be unable to determine if the access and deny state for the file allows any particular open until the delegation for the file has been returned.

A client failure or a network partition can result in failure to respond to a recall callback. In this case, the server will revoke the delegation which in turn will render useless any modified state still on the client.

Clients need to be aware that server implementors may enforce practical limitations on the number of delegations issued. Further, as there is no way to determine which delegations to revoke, the server is allowed to revoke any. If the server is implemented to revoke another delegation held by that client, then the client may be able to determine that a limit has been reached because each new delegation request results in a revoke. The client could then determine which delegations it may not need and preemptively release them.

10.2.1. Delegation Recovery

There are three situations that delegation recovery must deal with:

- Client reboot or restart
- Server reboot or restart
- Network partition (full or callback-only)

In the event the client reboots or restarts, the confirmation of a SETCLIENTID done with an nfs_client_id4 with a new verifier4 value will result in the release of byte-range locks and share reservations. Delegations, however, may be treated a bit differently.

There will be situations in which delegations will need to be reestablished after a client reboots or restarts. The reason for this is the client may have file data stored locally and this data was associated with the previously held delegations. The client will need to reestablish the appropriate file state on the server.

To allow for this type of client recovery, the server MAY allow delegations to be retained after other sort of locks are released. This implies that requests from other clients that conflict with these delegations will need to wait. Because the normal recall process may require significant time for the client to flush changed state to the server, other clients need to be prepared for delays that occur because of a conflicting delegation. In order to give clients a chance to get through the reboot process during which leases will not be renewed, the server MAY extend the period for delegation recovery beyond the typical lease expiration period. For open delegations, such delegations that are not released are reclaimed using OPEN with a claim type of CLAIM_DELEGATE_PREV. (See Section 10.5 and Section 15.18 for discussion of open delegation and the details of OPEN respectively).

A server MAY support a claim type of CLAIM_DELEGATE_PREV, but if it does, it MUST NOT remove delegations upon SETCLIENTID_CONFIRM and instead MUST make them available for client reclaim using CLAIM_DELEGATE_PREV. The server MAY NOT remove the delegations until either the client does a DELEGPURGE, or one lease period has elapsed from the time the later of the SETCLIENTID_CONFIRM or the last successful CLAIM_DELEGATE_PREV reclaim.

Note that the requirement stated above is not meant to imply that when the client is no longer obliged, as required above, to retain delegation information, that it should necessarily dispose of it.

Some specific cases are:

- When the period is terminated by the occurrence of DELEGPURGE, deletion of unreclaimed delegations is appropriate and desirable.

- When the period is terminated by a lease period elapsing without a successful CLAIM_DELEGATE_PREV reclaim, and that situation appears to be the result of a network partition (i.e., lease expiration has occurred), a server's lease expiration approach, possibly including the use of courtesy locks would normally provide for the retention of unreclaimed delegations. Even in the event that lease cancellation occurs, such delegation should be reclaimed using CLAIM_DELEGATE_PREV as part of network partition recovery.

- When the period of non-communicating is followed by a client reboot, unreclaimed delegations, should also be reclaimable by use of CLAIM_DELEGATE_PREV as part of client reboot recovery.

- When the period is terminated by a lease period elapsing without a successful CLAIM_DELEGATE_PREV reclaim, and lease renewal is occurring, the server may well conclude that unreclaimed delegations have been abandoned, and consider the situation as one in which an implied DELEGPURGE should be assumed.

A server that supports a claim type of CLAIM_DELEGATE_PREV MUST support the DELEGPURGE operation, and similarly a server that supports DELEGPURGE MUST support CLAIM_DELEGATE_PREV. A server which does not support CLAIM_DELEGATE_PREV MUST return NFS4ERR_NOTSUPP if the client attempts to use that feature or performs a DELEGPURGE operation.

Support for a claim type of CLAIM_DELEGATE_PREV, is often referred to as providing for "client-persistent delegations" in that they allow use of client persistent storage on the client to store data written by the client, even across a client restart. It should be noted that, with the optional exception noted below, this feature requires persistent storage to be used on the client and does not add to persistent storage requirements on the server.

One good way to think about client-persistent delegations is that for the most part, they function like "courtesy locks", with a special semantic adjustments to allow them to be retained across a client restart, which cause all other sorts of locks to be freed. Such locks are generally not retained across a server restart. The one exception is the case of simultaneous failure of the client and server and is discussed below.

When the server indicates support of CLAIM_DELEGATE_PREV (implicitly)

by returning NFS_OK to DELEGPURGE, a client with a write delegation, can use write-back caching for data to be written to the server, deferring the write-back, until such time as the delegation is recalled, possibly after intervening client restarts. Similarly, when the server indicates support of CLAIM_DELEGATE_PREV, a client with a read delegation and an open-for-write subordinate to that delegation, may be sure of the integrity of its persistently cached copy of the file after a client restart without specific verification of the change attribute.

When the server reboots or restarts, delegations are reclaimed (using the OPEN operation with CLAIM_PREVIOUS) in a similar fashion to byte-range locks and share reservations. However, there is a slight semantic difference. In the normal case, if the server decides that a delegation should not be granted, it performs the requested action (e.g., OPEN) without granting any delegation. For reclaim, the server grants the delegation but a special designation is applied so that the client treats the delegation as having been granted but recalled by the server. Because of this, the client has the duty to write all modified state to the server and then return the delegation. This process of handling delegation reclaim reconciles three principles of the NFSv4 protocol:

- Upon reclaim, a client reporting resources assigned to it by an earlier server instance must be granted those resources.

- The server has unquestionable authority to determine whether delegations are to be granted and, once granted, whether they are to be continued.

- The use of callbacks is not to be depended upon until the client has proven its ability to receive them.

When a client has more than a single open associated with a delegation, state for those additional opens can be established using OPEN operations of type CLAIM_DELEGATE_CUR. When these are used to establish opens associated with reclaimed delegations, the server MUST allow them when made within the grace period.

Situations in which there us a series of client and server restarts where there is no restart of both at the same time, are dealt with via a combination of CLAIM_DELEGATE_PREV and CLAIM_PREVIOUS reclaim cycles. Persistent storage is needed only on the client. For each server failure, a CLAIM_PREVIOUS reclaim cycle is done, while for each client restart, a CLAIM_DELEGATE_PREV reclaim cycle is done.

To deal with the possibility of simultaneous failure of client and server (e.g., a data center power outage), the server MAY

persistently store delegation information so that it can respond to a CLAIM_DELEGATE_PREV reclaim request which it receives from a restarting client. This is the one case in which persistent delegation state can be retained across a server restart. A server is not required to store this information, but if it does do so, it should do so for write delegations and for read delegations, during the pendency of which (across multiple client and/or server instances), some open-for-write was done as part of delegation. When the space to persistently record such information is limited, the server should recall delegations in this class in preference to keeping them active without persistent storage recording.

When a network partition occurs, delegations are subject to freeing by the server when the lease renewal period expires. This is similar to the behavior for locks and share reservations, and, as for locks and share reservations it may be modified by support for "courtesy locks" in which locks are not freed in the absence of a conflicting lock request. Whereas, for locks and share reservations, freeing of locks will occur immediately upon the appearance of a conflicting request, for delegations, the server may institute period during which conflicting requests are held off. Eventually the occurrence of a conflicting request from another client will cause revocation of the delegation.

A loss of the callback path (e.g., by later network configuration change) will have a similar effect in that it can also result in revocation of a delegation A recall request will fail and revocation of the delegation will result.

A client normally finds out about revocation of a delegation when it uses a stateid associated with a delegation and receives one of the errors NFS4ERR_EXPIRED, NFS4ERR_BAD_STATEID, or NFS4ERR_ADMIN_REVOKED (NFS4ERR_EXPIRED indicates that all lock state associated with the client has been lost). It also may find out about delegation revocation after a client reboot when it attempts to reclaim a delegation and receives NFS4ERR_EXPIRED. Note that in the case of a revoked OPEN_DELEGATE_WRITE delegation, there are issues because data may have been modified by the client whose delegation is revoked and separately by other clients. See Section 10.5.1 for a discussion of such issues. Note also that when delegations are revoked, information about the revoked delegation will be written by the server to stable storage (as described in Section 9.6). This is done to deal with the case in which a server reboots after revoking a delegation but before the client holding the revoked delegation is notified about the revocation.

Note that when there is a loss of a delegation, due to a network partition in which all locks associated with the lease are lost, the

client will also receive the error NFS4ERR_EXPIRED. This case can be distinguished from other situations in which delegations are revoked by seeing that the associated clientid becomes invalid so that NFS4ERR_STALE_CLIENTID is returned when it is used.

When NFS4ERR_EXPIRED Is returned, the server MAY retain information about the delegations held by the client, deleting those that are invalidated by a conflicting request. Retaining such information will allow the client to recover all non-invalidated delegations using the claim type CLAIM_DELEGATE_PREV, once the SETCLIENTID_CONFIRM is done to recover. Attempted recovery of a delegation that the client has no record of, typically because they were invalidated by conflicting requests, will get the error NFS4ERR_BAD_RECLAIM. Once a reclaim is attempted for all delegations that the client held, it SHOULD do a DELEGPURGE to allow any remaining server delegation information to be freed.

10.3. Data Caching

When applications share access to a set of files, they need to be implemented so as to take account of the possibility of conflicting access by another application. This is true whether the applications in question execute on different clients or reside on the same client.

Share reservations and byte-range locks are the facilities the NFS version 4 protocol provides to allow applications to coordinate access by providing mutual exclusion facilities. The NFSv4 protocol's data caching must be implemented such that it does not invalidate the assumptions that those using these facilities depend upon.

10.3.1. Data Caching and OPENs

In order to avoid invalidating the sharing assumptions that applications rely on, NFSv4 clients should not provide cached data to applications or modify it on behalf of an application when it would not be valid to obtain or modify that same data via a READ or WRITE operation.

Furthermore, in the absence of open delegation (see Section 10.4) two additional rules apply. Note that these rules are obeyed in practice by many NFSv2 and NFSv3 clients.

- First, cached data present on a client must be revalidated after doing an OPEN. Revalidating means that the client fetches the change attribute from the server, compares it with the cached change attribute, and if different, declares the cached data (as

well as the cached attributes) as invalid. This is to ensure that the data for the OPENed file is still correctly reflected in the client's cache. This validation must be done at least when the client's OPEN operation includes DENY=WRITE or BOTH thus terminating a period in which other clients may have had the opportunity to open the file with WRITE access. Clients may choose to do the revalidation more often (i.e., at OPENs specifying DENY=NONE) to parallel the NFSv3 protocol's practice for the benefit of users assuming this degree of cache revalidation. Since the change attribute is updated for data and metadata modifications, some client implementors may be tempted to use the time_modify attribute and not change to validate cached data, so that metadata changes do not spuriously invalidate clean data. The implementor is cautioned in this approach. The change attribute is guaranteed to change for each update to the file, whereas time_modify is guaranteed to change only at the granularity of the time_delta attribute. Use by the client's data cache validation logic of time_modify and not change runs the risk of the client incorrectly marking stale data as valid.

- Second, modified data must be flushed to the server before closing a file OPENed for write. This is complementary to the first rule. If the data is not flushed at CLOSE, the revalidation done after client OPENs as file is unable to achieve its purpose. The other aspect to flushing the data before close is that the data must be committed to stable storage, at the server, before the CLOSE operation is requested by the client. In the case of a server reboot or restart and a CLOSEd file, it may not be possible to retransmit the data to be written to the file. Hence, this requirement.

10.3.2. Data Caching and File Locking

For those applications that choose to use file locking instead of share reservations to exclude inconsistent file access, there is an analogous set of constraints that apply to client side data caching. These rules are effective only if the file locking is used in a way that matches in an equivalent way the actual READ and WRITE operations executed. This is as opposed to file locking that is based on pure convention. For example, it is possible to manipulate a two-megabyte file by dividing the file into two one-megabyte regions and protecting access to the two regions by file locks on bytes zero and one. A lock for write on byte zero of the file would represent the right to do READ and WRITE operations on the first region. A lock for write on byte one of the file would represent the right to do READ and WRITE operations on the second region. As long as all applications manipulating the file obey this convention, they will work on a local filesystem. However, they may not work with the

NFSv4 protocol unless clients refrain from data caching.

The rules for data caching in the file locking environment are:

- First, when a client obtains a file lock for a particular region, the data cache corresponding to that region (if any cached data exists) must be revalidated. If the change attribute indicates that the file may have been updated since the cached data was obtained, the client must flush or invalidate the cached data for the newly locked region. A client might choose to invalidate all of non-modified cached data that it has for the file but the only requirement for correct operation is to invalidate all of the data in the newly locked region.

- Second, before releasing a write lock for a region, all modified data for that region must be flushed to the server. The modified data must also be written to stable storage.

Note that flushing data to the server and the invalidation of cached data must reflect the actual byte ranges locked or unlocked. Rounding these up or down to reflect client cache block boundaries will cause problems if not carefully done. For example, writing a modified block when only half of that block is within an area being unlocked may cause invalid modification to the region outside the unlocked area. This, in turn, may be part of a region locked by another client. Clients can avoid this situation by synchronously performing portions of write operations that overlap that portion (initial or final) that is not a full block. Similarly, invalidating a locked area which is not an integral number of full buffer blocks would require the client to read one or two partial blocks from the server if the revalidation procedure shows that the data which the client possesses may not be valid.

The data that is written to the server as a prerequisite to the unlocking of a region must be written, at the server, to stable storage. The client may accomplish this either with synchronous writes or by following asynchronous writes with a COMMIT operation. This is required because retransmission of the modified data after a server reboot might conflict with a lock held by another client.

A client implementation may choose to accommodate applications which use byte-range locking in non-standard ways (e.g., using a byte-range lock as a global semaphore) by flushing to the server more data upon a LOCKU than is covered by the locked range. This may include modified data within files other than the one for which the unlocks are being done. In such cases, the client must not interfere with applications whose READs and WRITEs are being done only within the bounds of record locks which the application holds. For example, an

application locks a single byte of a file and proceeds to write that single byte. A client that chose to handle a LOCKU by flushing all modified data to the server could validly write that single byte in response to an unrelated unlock. However, it would not be valid to write the entire block in which that single written byte was located since it includes an area that is not locked and might be locked by another client. Client implementations can avoid this problem by dividing files with modified data into those for which all modifications are done to areas covered by an appropriate byte-range lock and those for which there are modifications not covered by a byte-range lock. Any writes done for the former class of files must not include areas not locked and thus not modified on the client.

10.3.3. Data Caching and Mandatory File Locking

Client side data caching needs to respect mandatory file locking when it is in effect. The presence of mandatory file locking for a given file is indicated when the client gets back NFS4ERR_LOCKED from a READ or WRITE on a file it has an appropriate share reservation for. When mandatory locking is in effect for a file, the client must check for an appropriate file lock for data being read or written. If a lock exists for the range being read or written, the client may satisfy the request using the client's validated cache. If an appropriate file lock is not held for the range of the read or write, the read or write request must not be satisfied by the client's cache and the request must be sent to the server for processing. When a read or write request partially overlaps a locked region, the request should be subdivided into multiple pieces with each region (locked or not) treated appropriately.

10.3.4. Data Caching and File Identity

When clients cache data, the file data needs to be organized according to the filesystem object to which the data belongs. For NFSv3 clients, the typical practice has been to assume for the purpose of caching that distinct filehandles represent distinct filesystem objects. The client then has the choice to organize and maintain the data cache on this basis.

In the NFSv4 protocol, there is now the possibility to have significant deviations from a "one filehandle per object" model because a filehandle may be constructed on the basis of the object's pathname. Therefore, clients need a reliable method to determine if two filehandles designate the same filesystem object. If clients were simply to assume that all distinct filehandles denote distinct objects and proceed to do data caching on this basis, caching inconsistencies would arise between the distinct client side objects which mapped to the same server side object.

By providing a method to differentiate filehandles, the NFSv4 protocol alleviates a potential functional regression in comparison with the NFSv3 protocol. Without this method, caching inconsistencies within the same client could occur and this has not been present in previous versions of the NFS protocol. Note that it is possible to have such inconsistencies with applications executing on multiple clients but that is not the issue being addressed here.

For the purposes of data caching, the following steps allow an NFSv4 client to determine whether two distinct filehandles denote the same server side object:

- If GETATTR directed to two filehandles returns different values of the fsid attribute, then the filehandles represent distinct objects.

- If GETATTR for any file with an fsid that matches the fsid of the two filehandles in question returns a unique_handles attribute with a value of TRUE, then the two objects are distinct.

- If GETATTR directed to the two filehandles does not return the fileid attribute for both of the handles, then it cannot be determined whether the two objects are the same. Therefore, operations which depend on that knowledge (e.g., client side data caching) cannot be done reliably. Note that if GETATTR does not return the fileid attribute for both filehandles, it will return it for neither of the filehandles, since the fsid for both filehandles is the same.

- If GETATTR directed to the two filehandles returns different values for the fileid attribute, then they are distinct objects.

- Otherwise they are the same object.

10.4. Open Delegation

When a file is being OPENed, the server may delegate further handling of opens and closes for that file to the opening client. Any such delegation is recallable, since the circumstances that allowed for the delegation are subject to change. In particular, the server may receive a conflicting OPEN from another client, the server must recall the delegation before deciding whether the OPEN from the other client may be granted. Making a delegation is up to the server and clients should not assume that any particular OPEN either will or will not result in an open delegation. The following is a typical set of conditions that servers might use in deciding whether OPEN should be delegated:

- The client must be able to respond to the server's callback requests. The server will use the CB_NULL procedure for a test of callback ability.

- The client must have responded properly to previous recalls.

- There must be no current open conflicting with the requested delegation.

- There should be no current delegation that conflicts with the delegation being requested.

- The probability of future conflicting open requests should be low based on the recent history of the file.

- The existence of any server-specific semantics of OPEN/CLOSE that would make the required handling incompatible with the prescribed handling that the delegated client would apply (see below).

There are two types of open delegations, OPEN_DELEGATE_READ and OPEN_DELEGATE_WRITE. A OPEN_DELEGATE_READ delegation allows a client to handle, on its own, requests to open a file for reading that do not deny read access to others. It MUST, however, continue to send all requests to open a file for writing to the server. Multiple OPEN_DELEGATE_READ delegations may be outstanding simultaneously and do not conflict. A OPEN_DELEGATE_WRITE delegation allows the client to handle, on its own, all opens. Only one OPEN_DELEGATE_WRITE delegation may exist for a given file at a given time and it is inconsistent with any OPEN_DELEGATE_READ delegations.

When a single client holds a OPEN_DELEGATE_READ delegation, it is assured that no other client may modify the contents or attributes of the file. If more than one client holds an OPEN_DELEGATE_READ delegation, then the contents and attributes of that file are not allowed to change. When a client has an OPEN_DELEGATE_WRITE delegation, it may modify the file data since no other client will be accessing the file's data. The client holding a OPEN_DELEGATE_WRITE delegation may only affect file attributes which are intimately connected with the file data: size, time_modify, change.

When a client has an open delegation, it does not send OPENs or CLOSEs to the server but updates the appropriate status internally. For a OPEN_DELEGATE_READ delegation, opens that cannot be handled locally (opens for write or that deny read access) must be sent to the server.

When an open delegation is made, the response to the OPEN contains an open delegation structure which specifies the following:

- the type of delegation (read or write)
- space limitation information to control flushing of data on close (OPEN_DELEGATE_WRITE delegation only, see Section 10.4.1)
- an nfsace4 specifying read and write permissions
- a stateid to represent the delegation for READ and WRITE

The delegation stateid is separate and distinct from the stateid for the OPEN proper. The standard stateid, unlike the delegation stateid, is associated with a particular lock-owner and will continue to be valid after the delegation is recalled and the file remains open.

When a request internal to the client is made to open a file and open delegation is in effect, it will be accepted or rejected solely on the basis of the following conditions. Any requirement for other checks to be made by the delegate should result in open delegation being denied so that the checks can be made by the server itself.

- The access and deny bits for the request and the file as described in Section 9.9.
- The read and write permissions as determined below.

The nfsace4 passed with delegation can be used to avoid frequent ACCESS calls. The permission check should be as follows:

- If the nfsace4 indicates that the open may be done, then it should be granted without reference to the server.
- If the nfsace4 indicates that the open may not be done, then an ACCESS request must be sent to the server to obtain the definitive answer.

The server may return an nfsace4 that is more restrictive than the actual ACL of the file. This includes an nfsace4 that specifies denial of all access. Note that some common practices such as mapping the traditional user "root" to the user "nobody" may make it incorrect to return the actual ACL of the file in the delegation response.

The use of delegation together with various other forms of caching creates the possibility that no server authentication will ever be performed for a given user since all of the user's requests might be satisfied locally. Where the client is depending on the server for authentication, the client should be sure authentication occurs for

each user by use of the ACCESS operation. This should be the case even if an ACCESS operation would not be required otherwise. As mentioned before, the server may enforce frequent authentication by returning an nfsace4 denying all access with every open delegation.

10.4.1. Open Delegation and Data Caching

OPEN delegation allows much of the message overhead associated with the opening and closing files to be eliminated. An open when an open delegation is in effect does not require that a validation message be sent to the server unless there exists a potential for conflict with the requested share mode. The continued endurance of the "OPEN_DELEGATE_READ delegation" provides a guarantee that no OPEN for write and thus no write has occurred that did not originate from this client. Similarly, when closing a file opened for write and if OPEN_DELEGATE_WRITE delegation is in effect, the data written does not have to be flushed to the server until the open delegation is recalled. The continued endurance of the open delegation provides a guarantee that no open and thus no read or write has been done by another client.

For the purposes of open delegation, READs and WRITEs done without an OPEN are treated as the functional equivalents of a corresponding type of OPEN. This refers to the READs and WRITEs that use the special stateids consisting of all zero bits or all one bits. Therefore, READs or WRITEs with a special stateid done by another client will force the server to recall a OPEN_DELEGATE_WRITE delegation. A WRITE with a special stateid done by another client will force a recall of OPEN_DELEGATE_READ delegations.

With delegations, a client is able to avoid writing data to the server when the CLOSE of a file is serviced. The file close system call is the usual point at which the client is notified of a lack of stable storage for the modified file data generated by the application. At the close, file data is written to the server and through normal accounting the server is able to determine if the available filesystem space for the data has been exceeded (i.e., server returns NFS4ERR_NOSPC or NFS4ERR_DQUOT). This accounting includes quotas. The introduction of delegations requires that a alternative method be in place for the same type of communication to occur between client and server.

In the delegation response, the server provides either the limit of the size of the file or the number of modified blocks and associated block size. The server must ensure that the client will be able to flush data to the server of a size equal to that provided in the original delegation. The server must make this assurance for all outstanding delegations. Therefore, the server must be careful in

its management of available space for new or modified data taking into account available filesystem space and any applicable quotas. The server can recall delegations as a result of managing the available filesystem space. The client should abide by the server's state space limits for delegations. If the client exceeds the stated limits for the delegation, the server's behavior is undefined.

Based on server conditions, quotas or available filesystem space, the server may grant OPEN_DELEGATE_WRITE delegations with very restrictive space limitations. The limitations may be defined in a way that will always force modified data to be flushed to the server on close.

With respect to authentication, flushing modified data to the server after a CLOSE has occurred may be problematic. For example, the user of the application may have logged off the client and unexpired authentication credentials may not be present. In this case, the client may need to take special care to ensure that local unexpired credentials will in fact be available. This may be accomplished by tracking the expiration time of credentials and flushing data well in advance of their expiration or by making private copies of credentials to assure their availability when needed.

10.4.2. Open Delegation and File Locks

When a client holds a OPEN_DELEGATE_WRITE delegation, lock operations may be performed locally. This includes those required for mandatory file locking. This can be done since the delegation implies that there can be no conflicting locks. Similarly, all of the revalidations that would normally be associated with obtaining locks and the flushing of data associated with the releasing of locks need not be done.

When a client holds a OPEN_DELEGATE_READ delegation, lock operations are not performed locally. All lock operations, including those requesting non-exclusive locks, are sent to the server for resolution.

10.4.3. Handling of CB_GETATTR

The server needs to employ special handling for a GETATTR where the target is a file that has a OPEN_DELEGATE_WRITE delegation in effect. The reason for this is that the client holding the OPEN_DELEGATE_WRITE delegation may have modified the data and the server needs to reflect this change to the second client that submitted the GETATTR. Therefore, the client holding the OPEN_DELEGATE_WRITE delegation needs to be interrogated. The server will use the CB_GETATTR operation. The only attributes that the

server can reliably query via CB_GETATTR are size and change.

Since CB_GETATTR is being used to satisfy another client's GETATTR request, the server only needs to know if the client holding the delegation has a modified version of the file. If the client's copy of the delegated file is not modified (data or size), the server can satisfy the second client's GETATTR request from the attributes stored locally at the server. If the file is modified, the server only needs to know about this modified state. If the server determines that the file is currently modified, it will respond to the second client's GETATTR as if the file had been modified locally at the server.

Since the form of the change attribute is determined by the server and is opaque to the client, the client and server need to agree on a method of communicating the modified state of the file. For the size attribute, the client will report its current view of the file size. For the change attribute, the handling is more involved.

For the client, the following steps will be taken when receiving a OPEN_DELEGATE_WRITE delegation:

- The value of the change attribute will be obtained from the server and cached. Let this value be represented by c.

- The client will create a value greater than c that will be used for communicating modified data is held at the client. Let this value be represented by d.

- When the client is queried via CB_GETATTR for the change attribute, it checks to see if it holds modified data. If the file is modified, the value d is returned for the change attribute value. If this file is not currently modified, the client returns the value c for the change attribute.

For simplicity of implementation, the client MAY for each CB_GETATTR return the same value d. This is true even if, between successive CB_GETATTR operations, the client again modifies in the file's data or metadata in its cache. The client can return the same value because the only requirement is that the client be able to indicate to the server that the client holds modified data. Therefore, the value of d may always be c + 1.

While the change attribute is opaque to the client in the sense that it has no idea what units of time, if any, the server is counting change with, it is not opaque in that the client has to treat it as an unsigned integer, and the server has to be able to see the results of the client's changes to that integer. Therefore, the server MUST

encode the change attribute in network order when sending it to the client. The client MUST decode it from network order to its native order when receiving it and the client MUST encode it network order when sending it to the server. For this reason, change is defined as an unsigned integer rather than an opaque array of bytes.

For the server, the following steps will be taken when providing a OPEN_DELEGATE_WRITE delegation:

- Upon providing a OPEN_DELEGATE_WRITE delegation, the server will cache a copy of the change attribute in the data structure it uses to record the delegation. Let this value be represented by sc.

- When a second client sends a GETATTR operation on the same file to the server, the server obtains the change attribute from the first client. Let this value be cc.

- If the value cc is equal to sc, the file is not modified and the server returns the current values for change, time_metadata, and time_modify (for example) to the second client.

- If the value cc is NOT equal to sc, the file is currently modified at the first client and most likely will be modified at the server at a future time. The server then uses its current time to construct attribute values for time_metadata and time_modify. A new value of sc, which we will call nsc, is computed by the server, such that nsc >= sc + 1. The server then returns the constructed time_metadata, time_modify, and nsc values to the requester. The server replaces sc in the delegation record with nsc. To prevent the possibility of time_modify, time_metadata, and change from appearing to go backward (which would happen if the client holding the delegation fails to write its modified data to the server before the delegation is revoked or returned), the server SHOULD update the file's metadata record with the constructed attribute values. For reasons of reasonable performance, committing the constructed attribute values to stable storage is OPTIONAL.

As discussed earlier in this section, the client MAY return the same cc value on subsequent CB_GETATTR calls, even if the file was modified in the client's cache yet again between successive CB_GETATTR calls. Therefore, the server must assume that the file has been modified yet again, and MUST take care to ensure that the new nsc it constructs and returns is greater than the previous nsc it returned. An example implementation's delegation record would satisfy this mandate by including a boolean field (let us call it "modified") that is set to FALSE when the delegation is granted, and an sc value set at the time of grant to the change attribute value.

The modified field would be set to TRUE the first time cc != sc, and would stay TRUE until the delegation is returned or revoked. The processing for constructing nsc, time_modify, and time_metadata would use this pseudo code:

```
    if (!modified) {
        do CB_GETATTR for change and size;

        if (cc != sc)
            modified = TRUE;
    } else {
        do CB_GETATTR for size;
    }

    if (modified) {
        sc = sc + 1;
        time_modify = time_metadata = current_time;
        update sc, time_modify, time_metadata into file's metadata;
    }
```

This would return to the client (that sent GETATTR) the attributes it requested, but make sure size comes from what CB_GETATTR returned. The server would not update the file's metadata with the client's modified size.

In the case that the file attribute size is different than the server's current value, the server treats this as a modification regardless of the value of the change attribute retrieved via CB_GETATTR and responds to the second client as in the last step.

This methodology resolves issues of clock differences between client and server and other scenarios where the use of CB_GETATTR break down.

It should be noted that the server is under no obligation to use CB_GETATTR and therefore the server MAY simply recall the delegation to avoid its use.

10.4.4. Recall of Open Delegation

The following events necessitate recall of an open delegation:

- Potentially conflicting OPEN request (or READ/WRITE done with "special" stateid)

- SETATTR issued by another client

- REMOVE request for the file

- RENAME request for the file as either source or target of the RENAME

Whether a RENAME of a directory in the path leading to the file results in recall of an open delegation depends on the semantics of the server filesystem. If that filesystem denies such RENAMEs when a file is open, the recall must be performed to determine whether the file in question is, in fact, open.

In addition to the situations above, the server may choose to recall open delegations at any time if resource constraints make it advisable to do so. Clients should always be prepared for the possibility of recall.

When a client receives a recall for an open delegation, it needs to update state on the server before returning the delegation. These same updates must be done whenever a client chooses to return a delegation voluntarily. The following items of state need to be dealt with:

- If the file associated with the delegation is no longer open and no previous CLOSE operation has been sent to the server, a CLOSE operation must be sent to the server.

- If a file has other open references at the client, then OPEN operations must be sent to the server. The appropriate stateids will be provided by the server for subsequent use by the client since the delegation stateid will not longer be valid. These OPEN requests are done with the claim type of CLAIM_DELEGATE_CUR. This will allow the presentation of the delegation stateid so that the client can establish the appropriate rights to perform the OPEN. (see Section 15.18 for details.)

- If there are granted file locks, the corresponding LOCK operations need to be performed. This applies to the OPEN_DELEGATE_WRITE delegation case only.

- For a OPEN_DELEGATE_WRITE delegation, if at the time of recall the file is not open for write, all modified data for the file must be flushed to the server. If the delegation had not existed, the client would have done this data flush before the CLOSE operation.

- For a OPEN_DELEGATE_WRITE delegation when a file is still open at the time of recall, any modified data for the file needs to be flushed to the server.

- With the OPEN_DELEGATE_WRITE delegation in place, it is possible that the file was truncated during the duration of the delegation. For example, the truncation could have occurred as a result of an OPEN UNCHECKED4 with a size attribute value of zero. Therefore, if a truncation of the file has occurred and this operation has not been propagated to the server, the truncation must occur before any modified data is written to the server.

In the case of OPEN_DELEGATE_WRITE delegation, file locking imposes some additional requirements. To precisely maintain the associated invariant, it is required to flush any modified data in any region for which a write lock was released while the OPEN_DELEGATE_WRITE delegation was in effect. However, because the OPEN_DELEGATE_WRITE delegation implies no other locking by other clients, a simpler implementation is to flush all modified data for the file (as described just above) if any write lock has been released while the OPEN_DELEGATE_WRITE delegation was in effect.

An implementation need not wait until delegation recall (or deciding to voluntarily return a delegation) to perform any of the above actions, if implementation considerations (e.g., resource availability constraints) make that desirable. Generally, however, the fact that the actual open state of the file may continue to change makes it not worthwhile to send information about opens and closes to the server, except as part of delegation return. Only in the case of closing the open that resulted in obtaining the delegation would clients be likely to do this early, since, in that case, the close once done will not be undone. Regardless of the client's choices on scheduling these actions, all must be performed before the delegation is returned, including (when applicable) the close that corresponds to the open that resulted in the delegation. These actions can be performed either in previous requests or in previous operations in the same COMPOUND request.

10.4.5. OPEN Delegation Race with CB_RECALL

The server informs the client of recall via a CB_RECALL. A race case which may develop is when the delegation is immediately recalled before the COMPOUND which established the delegation is returned to the client. As the CB_RECALL provides both a stateid and a filehandle for which the client has no mapping, it cannot honor the recall attempt. At this point, the client has two choices, either do not respond or respond with NFS4ERR_BADHANDLE. If it does not respond, then it runs the risk of the server deciding to not grant it further delegations.

If instead it does reply with NFS4ERR_BADHANDLE, then both the client and the server might be able to detect that a race condition is

occurring. The client can keep a list of pending delegations. When it receives a CB_RECALL for an unknown delegation, it can cache the stateid and filehandle on a list of pending recalls. When it is provided with a delegation, it would only use it if it was not on the pending recall list. Upon the next CB_RECALL, it could immediately return the delegation.

In turn, the server can keep track of when it issues a delegation and assume that if a client responds to the CB_RECALL with a NFS4ERR_BADHANDLE, then the client has yet to receive the delegation. The server SHOULD give the client a reasonable time both to get this delegation and to return it before revoking the delegation. Unlike a failed callback path, the server should periodically probe the client with CB_RECALL to see if it has received the delegation and is ready to return it.

When the server finally determines that enough time has lapsed, it SHOULD revoke the delegation and it SHOULD NOT revoke the lease. During this extended recall process, the server SHOULD be renewing the client lease. The intent here is that the client not pay too onerous a burden for a condition caused by the server.

10.4.6. Clients that Fail to Honor Delegation Recalls

A client may fail to respond to a recall for various reasons, such as a failure of the callback path from server to the client. The client may be unaware of a failure in the callback path. This lack of awareness could result in the client finding out long after the failure that its delegation has been revoked, and another client has modified the data for which the client had a delegation. This is especially a problem for the client that held a OPEN_DELEGATE_WRITE delegation.

The server also has a dilemma in that the client that fails to respond to the recall might also be sending other NFS requests, including those that renew the lease before the lease expires. Without returning an error for those lease renewing operations, the server leads the client to believe that the delegation it has is in force.

This difficulty is solved by the following rules:

- When the callback path is down, the server MUST NOT revoke the delegation if one of the following occurs:
  - The client has issued a RENEW operation and the server has returned an NFS4ERR_CB_PATH_DOWN error. The server MUST renew the lease for any byte-range locks and share reservations the

client has that the server has known about (as opposed to those locks and share reservations the client has established but not yet sent to the server, due to the delegation). The server SHOULD give the client a reasonable time to return its delegations to the server before revoking the client's delegations.

* The client has not issued a RENEW operation for some period of time after the server attempted to recall the delegation. This period of time MUST NOT be less than the value of the lease_time attribute.

o When the client holds a delegation, it cannot rely on operations, except for RENEW, that take a stateid, to renew delegation leases across callback path failures. The client that wants to keep delegations in force across callback path failures must use RENEW to do so.

10.4.7. Delegation Revocation

At the point a delegation is revoked, if there are associated opens on the client, the applications holding these opens need to be notified. This notification usually occurs by returning errors for READ/WRITE operations or when a close is attempted for the open file.

If no opens exist for the file at the point the delegation is revoked, then notification of the revocation is unnecessary. However, if there is modified data present at the client for the file, the user of the application should be notified. Unfortunately, it may not be possible to notify the user since active applications may not be present at the client. See Section 10.5.1 for additional details.

10.5. Data Caching and Revocation

When locks and delegations are revoked, the assumptions upon which successful caching depend are no longer guaranteed. For any locks or share reservations that have been revoked, the corresponding owner needs to be notified. This notification includes applications with a file open that has a corresponding delegation which has been revoked. Cached data associated with the revocation must be removed from the client. In the case of modified data existing in the client's cache, that data must be removed from the client without it being written to the server. As mentioned, the assumptions made by the client are no longer valid at the point when a lock or delegation has been revoked. For example, another client may have been granted a conflicting lock after the revocation of the lock at the first client. Therefore, the data within the lock range may have been modified by the other

client. Obviously, the first client is unable to guarantee to the application what has occurred to the file in the case of revocation.

Notification to a lock owner will in many cases consist of simply returning an error on the next and all subsequent READs/WRITEs to the open file or on the close. Where the methods available to a client make such notification impossible because errors for certain operations may not be returned, more drastic action such as signals or process termination may be appropriate. The justification for this is that an invariant for which an application depends on may be violated. Depending on how errors are typically treated for the client operating environment, further levels of notification including logging, console messages, and GUI pop-ups may be appropriate.

10.5.1. Revocation Recovery for Write Open Delegation

Revocation recovery for a OPEN_DELEGATE_WRITE delegation poses the special issue of modified data in the client cache while the file is not open. In this situation, any client which does not flush modified data to the server on each close must ensure that the user receives appropriate notification of the failure as a result of the revocation. Since such situations may require human action to correct problems, notification schemes in which the appropriate user or administrator is notified may be necessary. Logging and console messages are typical examples.

If there is modified data on the client, it must not be flushed normally to the server. A client may attempt to provide a copy of the file data as modified during the delegation under a different name in the filesystem name space to ease recovery. Note that when the client can determine that the file has not been modified by any other client, or when the client has a complete cached copy of file in question, such a saved copy of the client's view of the file may be of particular value for recovery. In other case, recovery using a copy of the file based partially on the client's cached data and partially on the server copy as modified by other clients, will be anything but straightforward, so clients may avoid saving file contents in these situations or mark the results specially to warn users of possible problems.

Saving of such modified data in delegation revocation situations may be limited to files of a certain size or might be used only when sufficient disk space is available within the target filesystem. Such saving may also be restricted to situations when the client has sufficient buffering resources to keep the cached copy available until it is properly stored to the target filesystem.

10.6. Attribute Caching

The attributes discussed in this section do not include named attributes. Individual named attributes are analogous to files and caching of the data for these needs to be handled just as data caching is for regular files. Similarly, LOOKUP results from an OPENATTR directory are to be cached on the same basis as any other pathnames and similarly for directory contents.

Clients may cache file attributes obtained from the server and use them to avoid subsequent GETATTR requests. Such caching is write through in that modification to file attributes is always done by means of requests to the server and should not be done locally and cached. The exception to this are modifications to attributes that are intimately connected with data caching. Therefore, extending a file by writing data to the local data cache is reflected immediately in the size as seen on the client without this change being immediately reflected on the server. Normally such changes are not propagated directly to the server but when the modified data is flushed to the server, analogous attribute changes are made on the server. When open delegation is in effect, the modified attributes may be returned to the server in the response to a CB_RECALL call.

The result of local caching of attributes is that the attribute caches maintained on individual clients will not be coherent. Changes made in one order on the server may be seen in a different order on one client and in a third order on a different client.

The typical filesystem application programming interfaces do not provide means to atomically modify or interrogate attributes for multiple files at the same time. The following rules provide an environment where the potential incoherency mentioned above can be reasonably managed. These rules are derived from the practice of previous NFS protocols.

- All attributes for a given file (per-fsid attributes excepted) are cached as a unit at the client so that no non-serializability can arise within the context of a single file.

- An upper time boundary is maintained on how long a client cache entry can be kept without being refreshed from the server.

- When operations are performed that change attributes at the server, the updated attribute set is requested as part of the containing RPC. This includes directory operations that update attributes indirectly. This is accomplished by following the modifying operation with a GETATTR operation and then using the results of the GETATTR to update the client's cached attributes.

Note that if the full set of attributes to be cached is requested by READDIR, the results can be cached by the client on the same basis as attributes obtained via GETATTR.

A client may validate its cached version of attributes for a file by fetching just both the change and time_access attributes and assuming that if the change attribute has the same value as it did when the attributes were cached, then no attributes other than time_access have changed. The reason why time_access is also fetched is because many servers operate in environments where the operation that updates change does not update time_access. For example, POSIX file semantics do not update access time when a file is modified by the write system call. Therefore, the client that wants a current time_access value should fetch it with change during the attribute cache validation processing and update its cached time_access.

The client may maintain a cache of modified attributes for those attributes intimately connected with data of modified regular files (size, time_modify, and change). Other than those three attributes, the client MUST NOT maintain a cache of modified attributes. Instead, attribute changes are immediately sent to the server.

In some operating environments, the equivalent to time_access is expected to be implicitly updated by each read of the content of the file object. If an NFS client is caching the content of a file object, whether it is a regular file, directory, or symbolic link, the client SHOULD NOT update the time_access attribute (via SETATTR or a small READ or READDIR request) on the server with each read that is satisfied from cache. The reason is that this can defeat the performance benefits of caching content, especially since an explicit SETATTR of time_access may alter the change attribute on the server. If the change attribute changes, clients that are caching the content will think the content has changed, and will re-read unmodified data from the server. Nor is the client encouraged to maintain a modified version of time_access in its cache, since this would mean that the client will either eventually have to write the access time to the server with bad performance effects, or it would never update the server's time_access, thereby resulting in a situation where an application that caches access time between a close and open of the same file observes the access time oscillating between the past and present. The time_access attribute always means the time of last access to a file by a read that was satisfied by the server. This way clients will tend to see only time_access changes that go forward in time.

10.7. Data and Metadata Caching and Memory Mapped Files

Some operating environments include the capability for an application to map a file's content into the application's address space. Each time the application accesses a memory location that corresponds to a block that has not been loaded into the address space, a page fault occurs and the file is read (or if the block does not exist in the file, the block is allocated and then instantiated in the application's address space).

As long as each memory mapped access to the file requires a page fault, the relevant attributes of the file that are used to detect access and modification (time_access, time_metadata, time_modify, and change) will be updated. However, in many operating environments, when page faults are not required these attributes will not be updated on reads or updates to the file via memory access (regardless whether the file is local file or is being access remotely). A client or server MAY fail to update attributes of a file that is being accessed via memory mapped I/O. This has several implications:

- If there is an application on the server that has memory mapped a file that a client is also accessing, the client may not be able to get a consistent value of the change attribute to determine whether its cache is stale or not. A server that knows that the file is memory mapped could always pessimistically return updated values for change so as to force the application to always get the most up to date data and metadata for the file. However, due to the negative performance implications of this, such behavior is OPTIONAL.

- If the memory mapped file is not being modified on the server, and instead is just being read by an application via the memory mapped interface, the client will not see an updated time_access attribute. However, in many operating environments, neither will any process running on the server. Thus NFS clients are at no disadvantage with respect to local processes.

- If there is another client that is memory mapping the file, and if that client is holding a OPEN_DELEGATE_WRITE delegation, the same set of issues as discussed in the previous two bullet items apply. So, when a server does a CB_GETATTR to a file that the client has modified in its cache, the response from CB_GETATTR will not necessarily be accurate. As discussed earlier, the client's obligation is to report that the file has been modified since the delegation was granted, not whether it has been modified again between successive CB_GETATTR calls, and the server MUST assume that any file the client has modified in cache has been modified again between successive CB_GETATTR calls. Depending on the

nature of the client's memory management system, this weak obligation may not be possible. A client MAY return stale information in CB_GETATTR whenever the file is memory mapped.

- The mixture of memory mapping and file locking on the same file is problematic. Consider the following scenario, where the page size on each client is 8192 bytes.
  - Client A memory maps first page (8192 bytes) of file X
  - Client B memory maps first page (8192 bytes) of file X
  - Client A write locks first 4096 bytes
  - Client B write locks second 4096 bytes
  - Client A, via a STORE instruction modifies part of its locked region.
  - Simultaneous to client A, client B issues a STORE on part of its locked region.

Here the challenge is for each client to resynchronize to get a correct view of the first page. In many operating environments, the virtual memory management systems on each client only know a page is modified, not that a subset of the page corresponding to the respective lock regions has been modified. So it is not possible for each client to do the right thing, which is to only write to the server that portion of the page that is locked. For example, if client A simply writes out the page, and then client B writes out the page, client A's data is lost.

Moreover, if mandatory locking is enabled on the file, then we have a different problem. When clients A and B issue the STORE instructions, the resulting page faults require a byte-range lock on the entire page. Each client then tries to extend their locked range to the entire page, which results in a deadlock.

Communicating the NFS4ERR_DEADLOCK error to a STORE instruction is difficult at best.

If a client is locking the entire memory mapped file, there is no problem with advisory or mandatory byte-range locking, at least until the client unlocks a region in the middle of the file.

Given the above issues the following are permitted:

- Clients and servers MAY deny memory mapping a file they know there are byte-range locks for.

- Clients and servers MAY deny a byte-range lock on a file they know is memory mapped.

- A client MAY deny memory mapping a file that it knows requires mandatory locking for I/O. If mandatory locking is enabled after the file is opened and mapped, the client MAY deny the application further access to its mapped file.

10.8. Name Caching

The results of LOOKUP and READDIR operations may be cached to avoid the cost of subsequent LOOKUP operations. Just as in the case of attribute caching, inconsistencies may arise among the various client caches. To mitigate the effects of these inconsistencies and given the context of typical filesystem APIs, an upper time boundary is maintained on how long a client name cache entry can be kept without verifying that the entry has not been made invalid by a directory change operation performed by another client.

When a client is not making changes to a directory for which there exist name cache entries, the client needs to periodically fetch attributes for that directory to ensure that it is not being modified. After determining that no modification has occurred, the expiration time for the associated name cache entries may be updated to be the current time plus the name cache staleness bound.

When a client is making changes to a given directory, it needs to determine whether there have been changes made to the directory by other clients. It does this by using the change attribute as reported before and after the directory operation in the associated change_info4 value returned for the operation. The server is able to communicate to the client whether the change_info4 data is provided atomically with respect to the directory operation. If the change values are provided atomically, the client is then able to compare the pre-operation change value with the change value in the client's name cache. If the comparison indicates that the directory was updated by another client, the name cache associated with the modified directory is purged from the client. If the comparison indicates no modification, the name cache can be updated on the client to reflect the directory operation and the associated timeout extended. The post-operation change value needs to be saved as the basis for future change_info4 comparisons.

As demonstrated by the scenario above, name caching requires that the client revalidate name cache data by inspecting the change attribute

of a directory at the point when the name cache item was cached. This requires that the server update the change attribute for directories when the contents of the corresponding directory is modified. For a client to use the change_info4 information appropriately and correctly, the server must report the pre and post operation change attribute values atomically. When the server is unable to report the before and after values atomically with respect to the directory operation, the server must indicate that fact in the change_info4 return value. When the information is not atomically reported, the client should not assume that other clients have not changed the directory.

10.9. Directory Caching

The results of READDIR operations may be used to avoid subsequent READDIR operations. Just as in the cases of attribute and name caching, inconsistencies may arise among the various client caches. To mitigate the effects of these inconsistencies, and given the context of typical filesystem APIs, the following rules should be followed:

- Cached READDIR information for a directory which is not obtained in a single READDIR operation must always be a consistent snapshot of directory contents. This is determined by using a GETATTR before the first READDIR and after the last of READDIR that contributes to the cache.

- An upper time boundary is maintained to indicate the length of time a directory cache entry is considered valid before the client must revalidate the cached information.

The revalidation technique parallels that discussed in the case of name caching. When the client is not changing the directory in question, checking the change attribute of the directory with GETATTR is adequate. The lifetime of the cache entry can be extended at these checkpoints. When a client is modifying the directory, the client needs to use the change_info4 data to determine whether there are other clients modifying the directory. If it is determined that no other client modifications are occurring, the client may update its directory cache to reflect its own changes.

As demonstrated previously, directory caching requires that the client revalidate directory cache data by inspecting the change attribute of a directory at the point when the directory was cached. This requires that the server update the change attribute for directories when the contents of the corresponding directory is modified. For a client to use the change_info4 information appropriately and correctly, the server must report the pre and post

operation change attribute values atomically. When the server is unable to report the before and after values atomically with respect to the directory operation, the server must indicate that fact in the change_info4 return value. When the information is not atomically reported, the client should not assume that other clients have not changed the directory.

11. Minor Versioning

To address the requirement of an NFS protocol that can evolve as the need arises, the NFSv4 protocol contains the rules and framework to allow for future minor changes or versioning.

The base assumption with respect to minor versioning is that any future accepted minor version must follow the IETF process and be documented in a standards track RFC. Therefore, each minor version number will correspond to an RFC. Minor version 0 of the NFS version 4 protocol is represented by this RFC. The COMPOUND and CB_COMPOUND procedures support the encoding of the minor version being requested by the client.

The following items represent the basic rules for the development of minor versions. Note that a future minor version may decide to modify or add to the following rules as part of the minor version definition.

1. Procedures are not added or deleted

   To maintain the general RPC model, NFSv4 minor versions will not add to or delete procedures from the NFS program.

2. Minor versions may add operations to the COMPOUND and CB_COMPOUND procedures.

   The addition of operations to the COMPOUND and CB_COMPOUND procedures does not affect the RPC model.

   1. Minor versions may append attributes to the bitmap4 that represents sets of attributes and to the fattr4 that represents sets of attribute values.

      This allows for the expansion of the attribute model to allow for future growth or adaptation.

   2. Minor version X must append any new attributes after the last documented attribute.

Since attribute results are specified as an opaque array of per-attribute XDR encoded results, the complexity of adding new attributes in the midst of the current definitions would be too burdensome.

3. Minor versions must not modify the structure of an existing operation's arguments or results.

   Again, the complexity of handling multiple structure definitions for a single operation is too burdensome. New operations should be added instead of modifying existing structures for a minor version.

   This rule does not preclude the following adaptations in a minor version.

   * adding bits to flag fields, such as new attributes to GETATTR's bitmap4 data type, and providing corresponding variants of opaque arrays, such as a notify4 used together with such bitmaps

   * adding bits to existing attributes like ACLs that have flag words

   * extending enumerated types (including NFS4ERR_*) with new values

4. Minor versions must not modify the structure of existing attributes.

5. Minor versions must not delete operations.

   This prevents the potential reuse of a particular operation "slot" in a future minor version.

6. Minor versions must not delete attributes.

7. Minor versions must not delete flag bits or enumeration values.

8. Minor versions may declare an operation MUST NOT be implement.

   Specifying that an operation MUST NOT be implemented is equivalent to obsoleting an operation. For the client, it means that the operation MUST NOT be sent to the server. For the server, an NFS error can be returned as opposed to "dropping" the request as an XDR decode error. This approach allows for the obsolescence of an operation while maintaining its structure so that a future minor version can reintroduce the operation.

1. Minor versions may declare that an attribute MUST NOT be implemented.

2. Minor versions may declare that a flag bit or enumeration value MUST NOT be implemented.

9. Minor versions may downgrade features from REQUIRED to RECOMMENDED, or RECOMMENDED to OPTIONAL.

10. Minor versions may upgrade features from OPTIONAL to RECOMMENDED or RECOMMENDED to REQUIRED.

11. A client and server that support minor version X SHOULD support minor versions 0 through X-1 as well.

12. Except for infrastructural changes, no new features may be introduced as REQUIRED in a minor version.

    This rule allows for the introduction of new functionality and forces the use of implementation experience before designating a feature as REQUIRED. On the other hand, some classes of features are infrastructural and have broad effects. Allowing infrastructural features to be RECOMMENDED or OPTIONAL complicates implementation of the minor version.

13. A client MUST NOT attempt to use a stateid, filehandle, or similar returned object from the COMPOUND procedure with minor version X for another COMPOUND procedure with minor version Y, where X != Y.

12. Internationalization

This chapter describes the string-handling aspects of the NFSv4 protocol, and how they address issues related to internationalization, including issues related to UTF-8, normalization, string preparation, case folding, and handling of internationalization issues related to domains.

The NFSv4 protocol needs to deal with internationalization, or I18N, with respect to file names and other strings as used within the protocol. The choice of string representation must allow for reasonable name/string access to clients, applications, and users which use various languages. The UTF-8 encoding of the UCS as defined by [8] allows for this type of access and follows the policy described in "IETF Policy on Character Sets and Languages", [9].

In implementing such policies, it is important to understand and

respect the nature of NFSv4 as a means by which client implementations may invoke operations on remote file systems. Server implementations act as a conduit to a range of file system implementations that the NFSv4 server typically invokes through a virtual-file-system interface.

Keeping this context in mind, one needs to understand that the file systems with which clients will be interacting will generally not be devoted solely to access using NFS version 4. Local access and its requirements will generally be important and often access over other remote file access protocols will be as well. It is generally a functional requirement in practice for the users of the NFSv4 protocol (although it may be formally out of scope for this document) for the implementation to allow files created by other protocols and by local operations on the file system to be accessed using NFS version 4 as well.

It also needs to be understood that a considerable portion of file name processing will occur within the implementation of the file system rather than within the limits of the NFSv4 server implementation per se. As a result, certain aspects of name processing may change as the locus of processing moves from file system to file system. As a result of these factors, the protocol cannot enforce uniformity of name-related processing upon NFSv4 server requests on the server as a whole. Because the server interacts with existing file system implementations, the same server handling will produce different behavior when interacting with different file system implementations. To attempt to require uniform behavior, and treat the the protocol server and the file system as a unified application, would considerably limit the usefulness of the protocol.

12.1. Use of UTF-8

As mentioned above, UTF-8 is used as a convenient way to encode Unicode which allows clients that have no internationalization requirements to avoid these issues since the mapping of ASCII names to UTF-8 is the identity.

12.1.1. Relation to Stringprep

RFC 3454 [10], otherwise known as "stringprep", documents a framework for using Unicode/UTF-8 in networking protocols, intended "to increase the likelihood that string input and string comparison work in ways that make sense for typical users throughout the world." A protocol conforming to this framework must define a profile of stringprep "in order to fully specify the processing options." NFSv4, while it does make normative references to stringprep and uses

elements of that framework, it does not, for reasons that are explained below, conform to that framework, for all of the strings that are used within it.

In addition to some specific issues which have caused stringprep to add confusion in handling certain characters for certain languages, there are a number of general reasons why stringprep profiles are not suitable for describing NFSv4.

- Restricting the character repertoire to Unicode 3.2, as required by stringprep is unduly constricting.

- Many of the character tables in stringprep are inappropriate because of this limited character repertoire, so that normative reference to stringprep is not desirable in many case and instead, we allow more flexibility in the definition of case mapping tables.

- Because of the presence of different file systems, the specifics of processing are not fully defined and some aspects that are are RECOMMENDED, rather than REQUIRED.

Despite these issues, in many cases the general structure of stringprep profiles, consisting of sections which deal with the applicability of the description, the character repertoire, character mapping, normalization, prohibited characters, and issues of the handling (i.e., possible prohibition) of bidirectional strings, is a convenient way to describe the string handling which is needed and will be used where appropriate.

12.1.2. Normalization, Equivalence, and Confusability

Unicode has defined several equivalence relationships among the set of possible strings. Understanding the nature and purpose of these equivalence relations is important to understand the handling of Unicode strings within NFSv4.

Some string pairs are thought as only differing in the way accents and other diacritics are encoded, as illustrated in the examples below. Such string pairs are called "canonically equivalent".

Such equivalence can occur when there are precomposed characters, as an alternative to encoding a base character in addition to a combining accent. For example, the character LATIN SMALL LETTER E WITH ACUTE (U+00E9) is defined as canonically equivalent to the string consisting of LATIN SMALL LETTER E followed by COMBINING ACUTE ACCENT (U+0065, U+0301).

When multiple combining diacritics are present, differences in the ordering are not reflected in resulting display and the strings are defined as canonically equivalent. For example, the string consisting of LATIN SMALL LETTER Q, COMBINING ACUTE ACCENT, COMBINING GRAVE ACCENT (U+0071, U+0301, U+0300) is canonically equivalent to the string consisting of LATIN SMALL LETTER Q, COMBINING GRAVE ACCENT, COMBINING ACUTE ACCENT (U+0071, U+0300, U+0301)

When both situations are present, the number of canonically equivalent strings can be greater. Thus, the following strings are all canonically equivalent:

LATIN SMALL LETTER E, COMBINING MACRON, ACCENT, COMBINING ACUTE ACCENT (U+0xxx, U+0304, U+0301)

LATIN SMALL LETTER E, COMBINING ACUTE ACCENT, COMBINING MACRON (U+0xxx, U+0301, U+0304)

LATIN SMALL LETTER E WITH MACRON, COMBINING ACUTE ACCENT (U+011E, U+0301)

LATIN SMALL LETTER E WITH ACUTE, COMBINING MACRON (U+00E9, U+0304)

LATIN SMALL LETTER E WITH MACRON AND ACUTE (U+1E16)

Additionally there is an equivalence relation of "compatibility equivalence". Two canonically equivalent strings are necessarily compatibility equivalent, although not the converse. An example of compatibility equivalent strings which are not canonically equivalent are GREEK CAPITAL LETTER OMEGA (U+03A9) and OHM SIGN (U+2129). These are identical in appearance while other compatibility equivalent strings are not. Another example would be "x2" and the two character string denoting x-squared which are clearly different in appearance although compatibility equivalent and not canonically equivalent. These have Unicode encodings LATIN SMALL LETTER X, DIGIT TWO (U+0078, U+0032) and LATIN SMALL LETTER X, SUPERSCRIPT TWO (U+0078, U+00B2),

One way to deal with these equivalence relations is via normalization. A normalization form maps all strings to a corresponding normalized string in such a fashion that all strings that are equivalent (canonically or compatibly, depending on the form) are mapped to the same value. Thus the image of the mapping is a subset of Unicode strings conceived as the representatives of the equivalence classes defined by the chosen equivalence relation.

In the NFSv4 protocol, handling of issues related to

internationalization with regard to normalization follows one of two basic patterns:

- For strings whose function is related to other internet standards, such as server and domain naming, the normalization form defined by the appropriate internet standards is used. For server and domain naming, this involves normalization form NFKC as specified in [3]

- For other strings, particular those passed by the server to file system implementations, normalization requirements are the province of the file system and the job of this specification is not to specify a particular form but to make sure that interoperability is maximized, even when clients and server-based file systems have different preferences.

A related but distinct issue concerns string confusability. This can occur when two strings (including single-character strings) having a similar appearance. There have been attempts to define uniform processing in an attempt to avoid such confusion (see stringprep [10]) but the results have often added confusion.

Some examples of possible confusions and proposed processing intended to reduce/avoid confusions:

- Deletion of characters believed to be invisible and appropriately ignored, justifying their deletion, including, WORD JOINER (U+2060), and the ZERO WIDTH SPACE (U+200B).

- Deletion of characters supposed to not bear semantics and only affect glyph choice, including the ZERO WIDTH NON-JOINER (U+200C) and the ZERO WIDTH JOINER (U+200D), where the deletion turns out to be a problem for Farsi speakers.

- Prohibition of space characters such as the EM SPACE (U+2003), the EN SPACE (U+2002), and the THIN SPACE (U+2009).

In addition, character pairs which appear very similar and could and often do result in confusion. In addition to what Unicode defines as "compatibility equivalence", there are a considerable number of additional character pairs that could cause confusion. This includes characters such as LATIN CAPITAL LETTER O (U+004F) and DIGIT ZERO (U+0030), and CYRILLIC SMALL LETTER ER (U+0440) LATIN SMALL LETTER P (U+0070) (also with MATHEMATICAL BOLD SMALL P (U+1D429) and GREEK SMALL LETTER RHO (U+1D56, for good measure).

NFSv4, as it does with normalization, takes a two-part approach to this issue:

- For strings whose function is related to other internet standards, such as server and domain naming, any string processing to address the confusability issue is defined by the appropriate internet standards is used. For server and domain naming, this is the responsibility of IDNA as described in [3].

- For other strings, particularly those passed by the server to file system implementations, any such preparation requirements including the choice of how, or whether to address the confusability issue, are the responsibility of the file system to define, and for this specification to try to add its own set would add unacceptably to complexity, and make many files accessible locally and by other remote file access protocols, inaccessible by NFSv4. This specification defines how the protocol maximizes interoperability in the face of different file system implementations. NFSv4 does allow file systems to map and to reject characters, including those likely to result in confusion, since file systems may choose to do such things. It defines what the client will see in such cases, in order to limit problems that can arise when a file name is created and it appears to have a different name from the one it is assigned when the name is created.

12.2. String Type Overview

12.2.1. Overall String Class Divisions

NFSv4 has to deal with a large set of different types of strings and because of the different role of each, internationalization issues will be different for each:

- For some types of strings, the fundamental internationalization-related decisions are the province of the file system or the security-handling functions of the server and the protocol's job is to establish the rules under which file systems and servers are allowed to exercise this freedom, to avoid adding to confusion.

- In other cases, the fundamental internationalization issues are the responsibility of other IETF groups and our job is simply to reference those and perhaps make a few choices as to how they are to be used (e.g., U-labels vs. A-labels).

- There are also cases in which a string has a small amount of NFSv4 processing which results in one or more strings being referred to one of the other categories.

We will divide strings to be dealt with into the following classes:

MIX: indicating that there is small amount of preparatory processing that either picks an internationalization handling mode or divides the string into a set of (two) strings with a different mode internationalization handling for each. The details are discussed in the section "Types with Pre-processing to Resolve Mixture Issues".

NIP: indicating that, for various reasons, there is no need for internationalization-specific processing to be performed. The specifics of the various string types handled in this way are described in the section "String Types without Internationalization Processing".

INET: indicating that the string needs to be processed in a fashion governed by non-NFS-specific internet specifications. The details are discussed in the section "Types with Processing Defined by Other Internet Areas".

NFS: indicating that the string needs to be processed in a fashion governed by NFSv4-specific considerations. The primary focus is on enabling flexibility for the various file systems to be accessed and is described in the section "String Types with NFS-specific Processing".

12.2.2. Divisions by Typedef Parent types

There are a number of different string types within NFSv4 and internationalization handling will be different for different types of strings. Each the types will be in one of four groups based on the parent type that specifies the nature of its relationship to utf8 and ascii.

utf8_expected/USHOULD: indicating that strings of this type SHOULD be UTF-8 but clients and servers will not check for valid UTF-8 encoding.

utf8val_RECOMMENDED4/UVSHOULD: indicating that strings of this type SHOULD be and generally will be in the form of the UTF-8 encoding of Unicode. Strings in most cases will be checked by the server for valid UTF-8 but for certain file systems, such checking may be inhibited.

utf8val_REQUIRED4/UVMUST: indicating that strings of this type MUST be in the form of the UTF-8 encoding of Unicode. Strings will be checked by the server for valid UTF-8 and the server SHOULD ensure that when sent to the client, they are valid UTF-8.

ascii_REQUIRED4/ASCII: indicating that strings of this type MUST be sent and validated as ASCII, and thus are automatically UTF-8. The processing of these string must ensure that they are only have ASCII characters but this need not be a separate step if any normally required check for validity inherently assures that only ASCII characters are present.

In those cases where UTF-8 is not required, USHOULD and UVSHOULD, and strings that are not valid UTF-8 are received and accepted, the receiver MUST NOT modify the strings. For example, setting particular bits such as the high-order bit to zero MUST NOT be done.

12.2.3. Individual Types and Their Handling

The first table outlines the handling for the primary string types, i.e., those not derived as a prefix or a suffix from a mixture type.

Type	Parent	Class	Explanation
comptag4	USHOULD	NIP	Tag expected to be UTF-8 but no validation by server or client is to be done.
component4	UVSHOULD	NFS	Should be utf8 but clients may need to access file systems with a different name structure, such as file systems that have non-utf8 names.
linktext4	UVSHOULD	NFS	Should be utf8 since text may include name components. Because of the need to access existing file systems, this check may be inhibited.
fattr4_mimetype	ASCII	NIP	All mime types are ascii so no specific utf8 processing is required, given that you are comparing to that list.

Table 5

There are a number of string types that are subject to preliminary processing. This processing may take the form either of selecting one of two possible forms based on the string contents or it in may consist of dividing the string into multiple conjoined strings each with different utf8-related processing.

Type	Parent	Class	Explanation
prin4	UVMUST	MIX	Consists of two parts separated by an at-sign, a prinpfx4 and a prinsfx4. These are described in the next table.
server4	UVMUST	MIX	Is either an IP address (serveraddr4) which has to be pure ascii or a server name svrname4, which is described immediately below.

Table 6

The last table describes the components of the compound types described above.

Type	Class	Def	Explanation
svraddr4	ASCII	NIP	Server as IP address, whether IPv4 or IPv6.
svrname4	UVMUST	INET	Server name as returned by server. Not sent by client, except in VERIFY/NVERIFY.
prinsfx4	UVMUST	INET	Suffix part of principal, in the form of a domain name.
prinpfx4	UVMUST	NFS	Must match one of a list of valid users or groups for that particular domain.

Table 7

12.3. Errors Related to Strings

When the client sends an invalid UTF-8 string in a context in which UTF-8 is REQUIRED, the server MUST return an NFS4ERR_INVAL error. Within the framework of the previous section, this applies to strings whose type is defined as utf8val_REQUIRED4 or ascii_REQUIRED4. When the client sends an invalid UTF-8 string in a context in which UTF-8 is RECOMMENDED and the server should test for UTF-8, the server SHOULD return an NFS4ERR_INVAL error. Within the framework of the previous section, this applies to strings whose type is defined as utf8val_RECOMMENDED4. These situations apply to cases in which inappropriate prefixes are detected and where the count includes trailing bytes that do not constitute a full UCS character.

Where the client-supplied string is valid UTF-8 but contains characters that are not supported by the server file system as a value for that string (e.g., names containing characters that have more than two octets on a file system that supports UCS-2 characters only, file name components containing slashes on file systems that do not allow them in file name components), the server MUST return an NFS4ERR_BADCHAR error.

Where a UTF-8 string is used as a file name component, and the file system, while supporting all of the characters within the name, does not allow that particular name to be used, the server should return the error NFS4ERR_BADNAME. This includes file system prohibitions of "." and ".." as file names for certain operations, and other such similar constraints. It does not include use of strings with non-preferred normalization modes.

Where a UTF-8 string is used as a file name component, the file system implementation MUST NOT return NFS4ERR_BADNAME, simply due to a normalization mismatch. In such cases the implementation SHOULD convert the string to its own preferred normalization mode before performing the operation. As a result, a client cannot assume that a file created with a name it specifies will have that name when the directory is read. It may have instead, the name converted to the file system's preferred normalization form.

Where a UTF-8 string is used as other than as file name component (or as symbolic link text) and the string does not meet the normalization requirements specified for it, the error NFS4ERR_INVAL is returned.

12.4. Types with Pre-processing to Resolve Mixture Issues

12.4.1. Processing of Principal Strings

Strings denoting principals (users or groups) MUST be UTF-8 but since they consist of a principal prefix, an at-sign, and a domain, all three of which either are checked for being UTF-8, or inherently are UTF-8, checking the string as a whole for being UTF-8 is not required. Although a server implementation may choose to make this check on the string as whole, for example in converting it to Unicode, the description within this document, will reflect a processing model in which such checking happens after the division into a principal prefix and suffix, the latter being in the form of a domain name.

The string should be scanned for at-signs. If there is more that one at-sign, the string is considered invalid. For cases in which there are no at-signs or the at-sign appears at the start or end of the string see Interpreting owner and owner_group. Otherwise, the

portion before the at-sign is dealt with as a prinpfx4 and the portion after is dealt with as a prinsfx4.

12.4.2. Processing of Server Id Strings

Server id strings typically appear in responses (as attribute values) and only appear in requests as an attribute value presented to VERIFY and NVERIFY. With that exception, they are not subject to server validation and possible rejection. It is not expected that clients will typically do such validation on receipt of responses but they may as a way to check for proper server behavior. The responsibility for sending correct UTF-8 strings is with the server.

Servers are identified by either server names or IP addresses. Once an id has been identified as an IP address, then there is no processing specific to internationalization to be done, since such an address must be ASCII to be valid.

12.5. String Types without Internationalization Processing

There are a number of types of strings which, for a number of different reasons, do not require any internationalization-specific handling, such as validation of UTF-8, normalization, or character mapping or checking. This does not necessarily mean that the strings need not be UTF-8. In some case, other checking on the string ensures that they are valid UTF-8, without doing any checking specific to internationalization.

The following are the specific types:

comptag4: strings are an aid to debugging and the sender should avoid confusion by not using anything but valid UTF-8. But any work validating the string or modifying it would only add complication to a mechanism whose basic function is best supported by making it not subject to any checking and having data maximally available to be looked at in a network trace.

fattr4_mimetype: strings need to be validated by matching against a list of valid mime types. Since these are all ASCII, no processing specific to internationalization is required since anything that does not match is invalid and anything which does not obey the rules of UTF-8 will not be ASCII and consequently will not match, and will be invalid.

svraddr4: strings, in order to be valid, need to be ASCII, but if you check them for validity, you have inherently checked that that they are ASCII and thus UTF-8.

12.6. Types with Processing Defined by Other Internet Areas

There are two types of strings which NFSv4 deals with whose processing is defined by other Internet standards, and where issues related to different handling choices by server operating systems or server file systems do not apply.

These are as follows:

- Server names as they appear in the fs_locations attribute. Note that for most purposes, such server names will only be sent by the server to the client. The exception is use of the fs_locations attribute in a VERIFY or NVERIFY operation.

- Principal suffixes which are used to denote sets of users and groups, and are in the form of domain names.

The general rules for handling all of these domain-related strings are similar and independent of role the of the sender or receiver as client or server although the consequences of failure to obey these rules may be different for client or server. The server can report errors when it is sent invalid strings, whereas the client will simply ignore invalid string or use a default value in their place.

The string sent SHOULD be in the form of a U-label although it MAY be in the form of an A-label or a UTF-8 string that would not map to itself when canonicalized by applying ToUnicode(ToASCII(...)). The receiver needs to be able to accept domain and server names in any of the formats allowed. The server MUST reject, using the the error NFS4ERR_INVAL, a string which is not valid UTF-8 or which begins with "xn--" and violates the rules for a valid A-label.

When a domain string is part of id@domain or group@domain, the server SHOULD map domain strings which are A-labels or are UTF-8 domain names which are not U-labels, to the corresponding U-label, using ToUnicode(domain) or ToUnicode(ToASCII(domain)). As a result, the domain name returned within a userid on a GETATTR may not match that sent when the userid is set using SETATTR, although when this happens, the domain will be in the form of a U-label. When the server does not map domain strings which are not U-labels into a U-label, which it MAY do, it MUST NOT modify the domain and the domain returned on a GETATTR of the userid MUST be the same as that used when setting the userid by the SETATTR.

The server MAY implement VERIFY and NVERIFY without translating internal state to a string form, so that, for example, a user principal which represents a specific numeric user id, will match a different principal string which represents the same numeric user id.

12.7. String Types with NFS-specific Processing

For a number of data types within NFSv4, the primary responsibility for internationalization-related handling is that of some entity other than the server itself (see below for details). In these situations, the primary responsibility of NFSv4 is to provide a framework in which that other entity (file system and server operating system principal naming framework) implements its own decisions while establishing rules to limit interoperability issues.

This pattern applies to the following data types:

- In the case of name components (strings of type component4), the server-side file system implementation (of which there may be more than one for a particular server) deals with internationalization issues, in a fashion that is appropriate to NFSv4, other remote file access protocols, and local file access methods. See "Handling of File Name Components" for the detailed treatment.

- In the case of link text strings (strings of type lintext4), the issues are similar, but file systems are restricted in the set of acceptable internationalization-related processing that they may do, principally because symbolic links may contain name components that, when used, are presented to other file systems and/or other servers. See "Processing of Link Text" for the detailed treatment.

- In the case of principal prefix strings, any decisions regarding internationalization are the responsibility of the server operating systems which may make its own rules regarding user and group name encoding. See "Processing of Principal Prefixes" for the detailed treatment.

12.7.1. Handling of File Name Components

There are a number of places within client and server where file name components are processed:

- On the client, file names may be processed as part of forming NFSv4 requests. Any such processing will reflect specific needs of the client's environment and will be treated as out-of-scope from the viewpoint of this specification.

- On the server, file names are processed as part of processing NFSv4 requests. In practice, parts of the processing will be implemented within the NFS version 4 server while other parts will be implemented within the file system. This processing is described in the sections below. These sections are organized in

a fashion parallel to a stringprep profile. The same sorts of topics are dealt with but they differ in that there is a wider range of possible processing choices.

- On the server, file name components might potentially be subject to processing as part of generating NFS version 4 responses. This specification assumes that this processing will be empty and that file name components will be copied verbatim at this point. The file name components may be modified as they appear in responses, relative to the values used in the request but this is only treated as reflecting changes made as part of request processing. For example, a change to a file name component made in processing a CREATE operation will be reflected in the READDIR since the files created will have names that reflect CREATE-time processing.

- On the client, responses will need to be properly dealt with and the relevant issues will be discussed in the sections below. Primarily, this will involve dealing with the fact that file name components received in responses may need to be processed to meet the requirements of the client's internal environment. This will mainly involve dealing with changes in name components possibly made by server processing. It also addresses other sorts of expected behavior that do not involve a returned component4, such as whether a LOOKUP finds a given component4 or whether a CREATE or OPEN finds that a specified name already exists.

12.7.1.1. Nature of Server Processing of Name Components in Request

The component4 type defines a potentially case sensitive string, typically of UTF-8 characters. Its use in NFS version 4 is for representing file name components. Since file systems can implement case insensitive file name handling, it can be used for both case sensitive and case insensitive file name handling, based on the attributes of the file system.

It may be the case that two valid distinct UTF-8 strings will be the same after the processing described below. In such a case, a server may either,

- disallow the creation of a second name if its post-processed form collides with that of an existing name, or

- allow the creation of the second name, but arrange so that after post processing, the second name is different than the post-processed form of the first name.

12.7.1.2. Character Repertoire for the Component4 Type

The RECOMMENDED character repertoire for file name components is a recent/current version of Unicode, as encoded via UTF-8. There are a number of alternate character repertoires which may be chosen by the server based on implementation constraints including the requirements of the file system being accessed.

Two important alternative repertoires are:

- One alternate character repertoire is to represent file name components as strings of bytes with no protocol-defined encoding of multi-byte characters. Most typically, implementations that support this single-byte alternative will make it available as an option set by an administrator for all file systems within a server or for some particular file systems. If a server accepts non-UTF-8 strings anywhere within a specific file system, then it MUST do so throughout the entire file system.

- Another alternate character repertoire is the set of codepoints, representable by the file system, most typically UCS-4.

Individual file system implementations may have more restricted character repertoires, as for example file system that only are capable of storing names consisting of UCS-2 characters. When this is the case, and the character repertoire is not restricted to single-byte characters, characters not within that repertoire are treated as prohibited and the error NFS4ERR_BADCHAR is returned by the server when that character is encountered.

Strings are intended to be in UTF-8 format and servers SHOULD return NFS4ERR_INVAL, as discussed above, when the characters sent are not valid UTF-8. When the character repertoire consists of single-byte characters, UTF-8 is not enforced. Such situations should be restricted to those where use is within a restricted environment where a single character mapping locale can be administratively enforced, allowing a file name to be treated as a string of bytes, rather than as a string of characters. Such an arrangement might be necessary when NFSv4 access to a file system containing names which are not valid UTF-8 needs to be provided.

However, in any of the following situations, file names have to be treated as strings of Unicode characters and servers MUST return NFS4ERR_INVAL when file names that are not in UTF-8 format:

- Case-insensitive comparisons are specified by the file system and any characters sent contain non-ASCII byte codes.

- Any normalization constraints are enforced by the server or file system implementation.

- The server accepts a given name when creating a file and reports a different one when the directory is being examined.

Much of the discussion below regarding normalization and silent deletion of characters within component4 strings is not applicable when the server does not enforce UTF-8 component4 strings and treats them as strings of bytes. A client may determine that a given filesystem is operating in this mode by performing a LOOKUP using a non-UTF-8 string, if NFS4ERR_INVAL is not returned, then name components will be treated as opaque and those sorts of modifications will not be seen.

12.7.1.3. Case-based Mapping Used for Component4 Strings

Case-based mapping is not always a required part of server processing of name components. However, if the NFSv4 file server supports the case_insensitive file system attribute, and if the case_insensitive attribute is true for a given file system, the NFS version 4 server MUST use the Unicode case mapping tables for the version of Unicode corresponding to the character repertoire. In the case where the character repertoire is UCS-2 or UCS-4, the case mapping tables from the latest available version of Unicode SHOULD be used.

If the case_preserving attribute is present and set to false, then the NFSv4 server MUST use the corresponding Unicode case mapping table to map case when processing component4 strings. Whether the server maps from lower to upper case or the upper to lower case is a matter for implementation choice.

Stringprep Table B.2 should not be used for these purpose since it is limited to Unicode version 3.2 and also because it erroneously maps the German ligature eszett to the string "ss", whereas later versions of Unicode contain both lower-case and upper-case versions of Eszett (SMALL LETTER SHARP S and CAPITAL LETTER SHARP S).

Clients should be aware that servers may have mapped SMALL LETTER SHARP S to the string "ss" when case-insensitive mapping is in effect, with result that file whose name contains SMALL LETTER SHARP S may have that character replaced by "ss" or "SS".

12.7.1.4. Other Mapping Used for Component4 Strings

Other than for issues of case mapping, an NFSv4 server SHOULD limit visible (i.e., those that change the name of file to reflect those mappings to those from from a subset of the stringprep table B.1.

Note particularly, the mappings from U+200C and U+200D to the empty string should be avoided, due to their undesirable effect on some strings in Farsi.

Table B.1 may be used but it should be used only if required by the local file system implementation. For example, if the file system in question accepts file names containing the MONGOLIAN TODO SOFT HYPHEN character (U+1806) and they are distinct from the corresponding file names with this character removed, then using Table B.1 will cause functional problems when clients attempt to interact with that file system. The NFSv4 server implementation including the filesystem MUST NOT silently remove characters not within Table B.1.

If an implementation wishes to eliminate other characters because it is believed that allowing component name versions that both include the character and do not have while otherwise the same, will contribute to confusion, it has two options:

- Treat the characters as prohibited and return NFS4ERR_BADCHAR.

- Eliminate the character as part of the name matching processing, while retaining it when a file is created. This would be analogous to file systems that are both case-insensitive and case-preserving,as discussed above, or those which are both normalization-insensitive and normalization-preserving, as discussed below. The handling will be insensitive to the presence of the chosen characters while preserving the presence or absence of such characters within names.

Note that the second of these choices is a desirable way to handle characters within table B.1, again with the exception of U+200C and U+200D, which can cause issues for Farsi.

In addition to modification due to normalization, discussed below, clients have to be able to deal with name modifications and other consequences of character mapping on the server, as discussed above.

12.7.1.5. Normalization Issues for Component Strings

The issues are best discussed separately for the server and the client. It is important to note that the server and client may have different approaches to this area, and that the server choice may not match the client operating environment. The issue of mismatches and how they may be best dealt with by the client is discussed in a later section.

12.7.1.5.1. Server Normalization Issues for Component Strings

The NFSv4 does not specify required use of a particular normalization form for component4 strings. Therefore, the server may receive unnormalized strings or strings that reflect either normalization form within protocol requests and responses. If the file system requires normalization, then the server implementation must normalize component4 strings within the protocol server before presenting the information to the local file system.

With regard to normalization, servers have the following choices, with the possibility that different choices may be selected for different file systems.

- Implement a particular normalization form, either NFC, or NFD, in which case file names received from a client are converted to that normalization form and as a consequence, the client will always receive names in that normalization form. If this option is chosen, then it is impossible to create two files in the same directory that have different names which map to the same name when normalized.

- Implement handling which is both normalization-insensitive and normalization-preserving. This makes it impossible to create two files in the same directory that have two different canonically equivalent names, i.e., names which map to the same name when normalized. However, unlike the previous option, clients will not have the names that they present modified to meet the server's normalization constraints.

- Implement normalization-sensitive handling without enforcing a normalization form constraint on file names. This exposes the client to the possibility that two files can be created in the same directory which have different names which map to the same name when normalized. This may be a significant issue when clients which use different normalization forms are used on the same file system, but this issue needs to be set against the difficulty of providing other sorts of normalization handling for some existing file systems.

12.7.1.5.2. Client Normalization Issues for Component Strings

The client, in processing name components, needs to deal with the fact that the server may impose normalization on file name components presented to it. As a result, a file can be created within a directory and that name be different from that sent by the client due to normalization at the server.

Client operating environments differ in their handling of canonically equivalent names. Some environments treat canonically equivalent strings as essentially equal and we will call these environments normalization-aware. Others, because of the pattern of their development with regard to these issues treat different strings as different, even if they are canonically equivalent. We call these normalization-unaware.

We discuss below issues that may arise when each of these types of environments interact with the various types of file systems, with regard to normalization handling. Note that complexity for the client is increased given that there are no file system attributes to determine the normalization handling present for that file system. Where the client has the ability to create files (file system not read-only and security allows it), attempting to create multiple files with canonically equivalent names and looking at success patterns and the names assigned by the server to these files can serve as a way to determine the relevant information.

Normalization-aware environments interoperate most normally with servers that either impose a given normalization form or those that implement name handling which is both normalization-insensitive and normalization-preserving name handling. However, clients need to be prepared to interoperate with servers that have normalization-sensitive file naming. In this situation, the client needs to be prepared for the fact that a directory may contain multiple names that it considers equivalent.

The following suggestions may be helpful in handling interoperability issues for normalization-aware client environments, when they interact with normalization-sensitive file systems.

When READDIR is done, the names returned may include names that do not match the client's normalization form, but instead are other names canonically equivalent to the normalized name.

When it can be determined that a normalization-insensitive server file system is not involved, the client can simply normalize filename components strings to its preferred normalization form.

When it cannot be determined that a normalization-insensitive server file system is not involved, the client is generally best advised to process incoming name components so as to allow all name components in a canonical equivalence class to be together. When only a single member of class exists, it should generally mapped directly to the preferred normalization form, whether the name was of that form or not.

When the client sees multiple names that are canonically equivalent, it is clear you have a file system which is normalization sensitive. Clients should generally replace each canonically equivalent name with one that appends some distinguishing suffix, usually including a number. The numbers should be assigned so that each distinct possible name with the set of canonically equivalent names has an assigned numeric value. Note that for some cases in which there are multiple instances of strings that might be composed or decomposed and/or situations with multiple diacritics to be applied to the same character, the class might be large.

When interacting with a normalization-sensitive filesystem, it may be that the environment contains clients or implementations local to the OS in which the file system is embedded, which use a different normalization form. In such situations, a LOOKUP may well fail, even though the directory contains a name canonically equivalent to the name sought. One solution to this problem is to re-do the LOOKUP in that situation with name converted to the alternate normalization form.

In the case in which normalization-unaware clients are involved in the mix, LOOKUP can fail and then the second LOOKUP, described above can also fail, even though there may well be a canonically equivalent name in the directory. One possible approach in that case is to use a READDIR to find the equivalent name and lookup that, although this can greatly add to client implementation complexity.

When interacting with a normalization-sensitive filesystem, the situation where the environment contains clients or implementations local to the OS in which the file system is embedded, which use a different normalization form can also cause issues when a file (or symlink or directory, etc.) is being created. In such cases, you may be able to create an object of the specified name even though, the directory contains a canonically equivalent name. Similar issues can occur with LINK and RENAME. The client can't really do much about such situations, except be aware that they may occur. That's one of the reasons normalization-sensitive server file system implementations can be problematic to use when internationalization issues are important.

Normalization-unaware environments interoperate most normally with servers that implement normalization-sensitive file naming. However, clients need to be prepared to interoperate with servers that impose a given normalization form or that implement name handling which is both normalization-insensitive and normalization-preserving. In the

former case, a file created with a given name may find it changed to a different (although related name). In both cases, the client will have to deal with the fact that it is unable to create two names within a directory that are canonically equivalent.

Note that although the client implementation itself and the kernel implementation may be normalization-unaware, treating name components as strings not subject to normalization, the environment as a whole may be normalization-aware if commonly used libraries result in an application environment where a single normalization form is used throughout. Because of this, normalization-unaware environments may be relatively rare.

The following suggestions may be helpful in handling interoperability issues for truly normalization-unaware client environments, when they interact with file systems other than those which are normalization-sensitive. The issues tend to be the inverse of those for normalization-aware environments. The implementer should be careful not to erroneously treat the environment as normalization-unaware, based solely on the details of the kernel implementation.

Unless the file system is normalization-preserving, when files (or other objects) are created, the object name as reported by a READDIR of the associated directory may show a name different than the one used to create the object. This behavior is something that the client has to accept. Since it has no preferred normalization form, it has no way of converting the name to a preferred form.

In situations where there is an attempt to create multiple objects in the same directory which have canonically-equivalent names. these file systems will either report that an object of name already exists or simply open a file of that other name.

If it desired to have those two objects in the same directory, the names must be made not canonically equivalent. It is possible to append some distinguishing character to the name of the second object but in clients having a typical file API (such as POSIX), the fact that the name change occurred cannot be propagated back to the requester.

In cases where a client is application-specific, it may be possible for it to deal with such a collision by modifying the name and taking note of the changed name.

12.7.1.6. Prohibited Characters for Component Names

The NFSv4 protocol does not specify particular characters that may not appear in component names. File systems may have their own set of prohibited characters for which the error NFS4ERR_BADCHAR should be returned by the server. Clients need to be prepared for this error to occur whenever file name components are presented to the server.

Clients whose character repertoire for acceptable characters in file name components is smaller than the entire scope of UCS-4 may need to deal with names returned by the server that contain characters outside that repertoire. It is up to the client whether it simply ignores these files or modifies the name to meet its own rules for acceptable names.

Clients may encounter names that do not consist of valid UTF-8, if they interact with servers configured to allow this option. They are not required to deal with this case and may treat the server as not functioning correctly, or they may handle this as normal. Clients will normally make this a configuration option. As discussed above, a client can determine whether a particular file system is being supported by the server in this mode by issuing a LOOKUP specifying a name which is not valid UTF-8 and seeing if NFS4ERR_INVAL is returned.

12.7.1.7. Bidirectional String Checking for Component Names

The NFSv4 protocol does not require processing of component names to check for and reject bidirectional strings. Such processing may be a part of the file system implementation but if so, its particular form will be defined by the file system implementation. When strings are rejected on this basis, the error NFS4ERR_BADNAME would be returned.

Clients need to be prepared for the fact that the server may reject a file name component if it consists of a bidirectional string, returning NFS4ERR_BADNAME.

Clients may encounter names with bidirectional strings returned in responses from the server. If clients treat such strings as not valid file name components, it is up to the client whether it simply ignores these files or modifies the name component to meet its own rules for acceptable name component strings.

12.7.2. Processing of Link Text

Symbolic link text is defined as utf8val_RECOMMENDED4 and therefore the server SHOULD validate link text on a CREATE and return

NFS4ERR_INVAL if it is is not valid UTF-8. Note that file systems which treat names as strings of byte are an exception for which such validation need not be done. One other situation in which an NFSv4 might choose (or be configured) not to make such a check is when links within file system reference names in another which is configured to treat names as strings of bytes.

On the other hand, UTF-8 validation of symbolic link text need not be done on the data resulting from a READLINK. Such data might have been stored by an NFS Version 4 server configured to allow non-UTF-8 link text or it might have resulted from symbolic link text stored via local file system access or access via another remote file access protocol.

Note that because of the role of the symbolic link, as data stored and read by the user, other sorts of validations or modifications should not be done. Note that when component names with the symbolic link text are used, such checks and modifications will be done at that time. In particular,

- Limitation of the character repertoire MUST NOT be done. This includes limitations to reflect a particular version of Unicode, or the inability of any particularly file system to store characters beyond UCS-2.

- Name mapping, whether for case folding or otherwise MUST NOT be done.

- Checks for a type of normalization or normalization to a particular form MUST NOT be done.

- Checks for specific characters excluded by the server or file system MUST NOT be done.

- Checks for bidirectional strings MUST NOT be done.

12.7.3. Processing of Principal Prefixes

As mentioned above, users and groups are designated as a particular string at a specified domain. Servers will recognize a set of valid principals for one or more domains. With regard to the handling of these strings, the following rules MUST be followed

- The string MUST be checked by the server for valid UTF-8 and the error NFS4ERR_INVAL returned if it is not valid.

- The character repertoire for the principal prefix string should be limited to a current version of Unicode when the server is

implemented. However, the client cannot be assured that all characters it receives as part of a user or group attribute are those that are defined in the Unicode version it expects to work with.

- o No character mapping is to be done, as for example table B.1 in stringprep, and no case mapping is to be done. The user and group names are to be treated as case-sensitive.

- o Strings must not be rejected based on their normalization. Servers should do normalization insensitive matching in converting a user to group to an internal id. The client cannot assume that the server preserves normalization so a user set to one string value may be returned as a string which differs in normalization and the client must be prepared to deal with that, by, for example, normalizing the string to the client's preferred form.

- o There are no checks for specific invalid characters but servers may limit the characters, with the result that any principal presented by the client which has such a characters is treated as invalid.

- o Specific checks for bidirectional strings are not done but servers may limit the principal prefix strings to those which are unidirectional or are of a certain direction, with the result that any principal presented by the client which done not meet that criterion will be treated as invalid.

13. Error Values

NFS error numbers are assigned to failed operations within a Compound (COMPOUND or CB_COMPOUND) request. A Compound request contains a number of NFS operations that have their results encoded in sequence in a Compound reply. The results of successful operations will consist of an NFS4_OK status followed by the encoded results of the operation. If an NFS operation fails, an error status will be entered in the reply and the Compound request will be terminated.

13.1. Error Definitions

Protocol Error Definitions

Error	Number	Description
NFS4_OK	0	Section 13.1.3.1
NFS4ERR_ACCESS	13	Section 13.1.6.1

NFS4ERR_ATTRNOTSUPP	10032	Section 13.1.11.1
NFS4ERR_ADMIN_REVOKED	10047	Section 13.1.5.1
NFS4ERR_BADCHAR	10040	Section 13.1.7.1
NFS4ERR_BADHANDLE	10001	Section 13.1.2.1
NFS4ERR_BADNAME	10041	Section 13.1.7.2
NFS4ERR_BADOWNER	10039	Section 13.1.11.2
NFS4ERR_BADTYPE	10007	Section 13.1.4.1
NFS4ERR_BADXDR	10036	Section 13.1.1.1
NFS4ERR_BAD_COOKIE	10003	Section 13.1.1.2
NFS4ERR_BAD_RANGE	10042	Section 13.1.8.1
NFS4ERR_BAD_SEQID	10026	Section 13.1.8.2
NFS4ERR_BAD_STATEID	10025	Section 13.1.5.2
NFS4ERR_CLID_INUSE	10017	Section 13.1.10.1
NFS4ERR_DEADLOCK	10045	Section 13.1.8.3
NFS4ERR_DELAY	10008	Section 13.1.1.3
NFS4ERR_DENIED	10010	Section 13.1.8.4
NFS4ERR_DQUOT	69	Section 13.1.4.2
NFS4ERR_EXIST	17	Section 13.1.4.3
NFS4ERR_EXPIRED	10011	Section 13.1.5.3
NFS4ERR_FBIG	27	Section 13.1.4.4
NFS4ERR_FHEXPIRED	10014	Section 13.1.2.2
NFS4ERR_FILE_OPEN	10046	Section 13.1.4.5
NFS4ERR_GRACE	10013	Section 13.1.9.1
NFS4ERR_INVAL	22	Section 13.1.1.4
NFS4ERR_IO	5	Section 13.1.4.6
NFS4ERR_ISDIR	21	Section 13.1.2.3
NFS4ERR_LEASE_MOVED	10031	Section 13.1.5.4
NFS4ERR_LOCKED	10012	Section 13.1.8.5
NFS4ERR_LOCKS_HELD	10037	Section 13.1.8.6
NFS4ERR_LOCK_NOTSUPP	10043	Section 13.1.8.7
NFS4ERR_LOCK_RANGE	10028	Section 13.1.8.8
NFS4ERR_MINOR_VERS_MISMATCH	10021	Section 13.1.3.2
NFS4ERR_MLINK	31	Section 13.1.4.7
NFS4ERR_MOVED	10019	Section 13.1.2.4
NFS4ERR_NAMETOOLONG	63	Section 13.1.7.3
NFS4ERR_NOENT	2	Section 13.1.4.8
NFS4ERR_NOFILEHANDLE	10020	Section 13.1.2.5
NFS4ERR_NOSPC	28	Section 13.1.4.9
NFS4ERR_NOTDIR	20	Section 13.1.2.6
NFS4ERR_NOTEMPTY	66	Section 13.1.4.10
NFS4ERR_NOTSUPP	10004	Section 13.1.1.5
NFS4ERR_NOT_SAME	10027	Section 13.1.11.3
NFS4ERR_NO_GRACE	10033	Section 13.1.9.2
NFS4ERR_NXIO	6	Section 13.1.4.11
NFS4ERR_OLD_STATEID	10024	Section 13.1.5.5
NFS4ERR_OPENMODE	10038	Section 13.1.8.9
NFS4ERR_OP_ILLEGAL	10044	Section 13.1.3.3
NFS4ERR_PERM	1	Section 13.1.6.2

NFS4ERR_RECLAIM_BAD	10034	Section 13.1.9.3
NFS4ERR_RECLAIM_CONFLICT	10035	Section 13.1.9.4
NFS4ERR_RESOURCE	10018	Section 13.1.3.4
NFS4ERR_RESTOREFH	10030	Section 13.1.4.12
NFS4ERR_ROFS	30	Section 13.1.4.13
NFS4ERR_SAME	10009	Section 13.1.11.4
NFS4ERR_SERVERFAULT	10006	Section 13.1.1.6
NFS4ERR_STALE	70	Section 13.1.2.7
NFS4ERR_STALE_CLIENTID	10022	Section 13.1.10.2
NFS4ERR_STALE_STATEID	10023	Section 13.1.5.6
NFS4ERR_SYMLINK	10029	Section 13.1.2.8
NFS4ERR_TOOSMALL	10005	Section 13.1.1.7
NFS4ERR_WRONGSEC	10016	Section 13.1.6.3
NFS4ERR_XDEV	18	Section 13.1.4.14

Table 8

13.1.1. General Errors

This section deals with errors that are applicable to a broad set of different purposes.

13.1.1.1. NFS4ERR_BADXDR (Error Code 10036)

The arguments for this operation do not match those specified in the XDR definition. This includes situations in which the request ends before all the arguments have been seen. Note that this error applies when fixed enumerations (these include booleans) have a value within the input stream which is not valid for the enum. A replier may pre-parse all operations for a Compound procedure before doing any operation execution and return RPC-level XDR errors in that case.

13.1.1.2. NFS4ERR_BAD_COOKIE (Error Code 10003)

Used for operations that provide a set of information indexed by some quantity provided by the client or cookie sent by the server for an earlier invocation. Where the value cannot be used for its intended purpose, this error results.

13.1.1.3. NFS4ERR_DELAY (Error Code 10008)

For any of a number of reasons, the replier could not process this operation in what was deemed a reasonable time. The client should wait and then try the request with a new RPC transaction ID.

Some example of situations that might lead to this situation:

- A server that supports hierarchical storage receives a request to process a file that had been migrated.

- An operation requires a delegation recall to proceed and waiting for this delegation recall makes processing this request in a timely fashion impossible.

13.1.1.4. NFS4ERR_INVAL (Error Code 22)

The arguments for this operation are not valid for some reason, even though they do match those specified in the XDR definition for the request.

13.1.1.5. NFS4ERR_NOTSUPP (Error Code 10004)

Operation not supported, either because the operation is an OPTIONAL one and is not supported by this server or because the operation MUST NOT be implemented in the current minor version.

13.1.1.6. NFS4ERR_SERVERFAULT (Error Code 10006)

An error occurred on the server which does not map to any of the specific legal NFSv4 protocol error values. The client should translate this into an appropriate error. UNIX clients may choose to translate this to EIO.

13.1.1.7. NFS4ERR_TOOSMALL (Error Code 10005)

Used where an operation returns a variable amount of data, with a limit specified by the client. Where the data returned cannot be fit within the limit specified by the client, this error results.

13.1.2. Filehandle Errors

These errors deal with the situation in which the current or saved filehandle, or the filehandle passed to PUTFH intended to become the current filehandle, is invalid in some way. This includes situations in which the filehandle is a valid filehandle in general but is not of the appropriate object type for the current operation.

Where the error description indicates a problem with the current or saved filehandle, it is to be understood that filehandles are only checked for the condition if they are implicit arguments of the operation in question.

13.1.2.1. NFS4ERR_BADHANDLE (Error Code 10001)

Illegal NFS filehandle for the current server. The current file handle failed internal consistency checks. Once accepted as valid (by PUTFH), no subsequent status change can cause the filehandle to generate this error.

13.1.2.2. NFS4ERR_FHEXPIRED (Error Code 10014)

A current or saved filehandle which is an argument to the current operation is volatile and has expired at the server.

13.1.2.3. NFS4ERR_ISDIR (Error Code 21)

The current or saved filehandle designates a directory when the current operation does not allow a directory to be accepted as the target of this operation.

13.1.2.4. NFS4ERR_MOVED (Error Code 10019)

The file system which contains the current filehandle object is not present at the server. It may have been relocated, migrated to another server or may have never been present. The client may obtain the new file system location by obtaining the "fs_locations" or attribute for the current filehandle. For further discussion, refer to Section 7.

13.1.2.5. NFS4ERR_NOFILEHANDLE (Error Code 10020)

The logical current or saved filehandle value is required by the current operation and is not set. This may be a result of a malformed COMPOUND operation (i.e., no PUTFH or PUTROOTFH before an operation that requires the current filehandle be set).

13.1.2.6. NFS4ERR_NOTDIR (Error Code 20)

The current (or saved) filehandle designates an object which is not a directory for an operation in which a directory is required.

13.1.2.7. NFS4ERR_STALE (Error Code 70)

The current or saved filehandle value designating an argument to the current operation is invalid. The file referred to by that filehandle no longer exists or access to it has been revoked.

13.1.2.8. NFS4ERR_SYMLINK (Error Code 10029)

The current filehandle designates a symbolic link when the current operation does not allow a symbolic link as the target.

13.1.3. Compound Structure Errors

This section deals with errors that relate to overall structure of a Compound request (by which we mean to include both COMPOUND and CB_COMPOUND), rather than to particular operations.

There are a number of basic constraints on the operations that may appear in a Compound request.

13.1.3.1. NFS_OK (Error code 0)

Indicates the operation completed successfully, in that all of the constituent operations completed without error.

13.1.3.2. NFS4ERR_MINOR_VERS_MISMATCH (Error code 10021)

The minor version specified is not one that the current listener supports. This value is returned in the overall status for the Compound but is not associated with a specific operation since the results must specify a result count of zero.

13.1.3.3. NFS4ERR_OP_ILLEGAL (Error Code 10044)

The operation code is not a valid one for the current Compound procedure. The opcode in the result stream matched with this error is the ILLEGAL value, although the value that appears in the request stream may be different. Where an illegal value appears and the replier pre-parses all operations for a Compound procedure before doing any operation execution, an RPC-level XDR error may be returned in this case.

13.1.3.4. NFS4ERR_RESOURCE (Error Code 10018)

For the processing of the Compound procedure, the server may exhaust available resources and cannot continue processing operations within the Compound procedure. This error will be returned from the server in those instances of resource exhaustion related to the processing of the Compound procedure.

13.1.4. File System Errors

These errors describe situations which occurred in the underlying file system implementation rather than in the protocol or any NFSv4.x

feature.

13.1.4.1. NFS4ERR_BADTYPE (Error Code 10007)

An attempt was made to create an object with an inappropriate type specified to CREATE. This may be because the type is undefined, because it is a type not supported by the server, or because it is a type for which create is not intended such as a regular file or named attribute, for which OPEN is used to do the file creation.

13.1.4.2. NFS4ERR_DQUOT (Error Code 19)

Resource (quota) hard limit exceeded. The user's resource limit on the server has been exceeded.

13.1.4.3. NFS4ERR_EXIST (Error Code 17)

A file of the specified target name (when creating, renaming or linking) already exists.

13.1.4.4. NFS4ERR_FBIG (Error Code 27)

File too large. The operation would have caused a file to grow beyond the server's limit.

13.1.4.5. NFS4ERR_FILE_OPEN (Error Code 10046)

The operation is not allowed because a file involved in the operation is currently open. Servers may, but are not required to disallow linking-to, removing, or renaming open files.

13.1.4.6. NFS4ERR_IO (Error Code 5)

Indicates that an I/O error occurred for which the file system was unable to provide recovery.

13.1.4.7. NFS4ERR_MLINK (Error Code 31)

The request would have caused the server's limit for the number of hard links a file may have to be exceeded.

13.1.4.8. NFS4ERR_NOENT (Error Code 2)

Indicates no such file or directory. The file or directory name specified does not exist.

13.1.4.9. NFS4ERR_NOSPC (Error Code 28)

Indicates no space left on device. The operation would have caused the server's file system to exceed its limit.

13.1.4.10. NFS4ERR_NOTEMPTY (Error Code 66)

An attempt was made to remove a directory that was not empty.

13.1.4.11. NFS4ERR_NXIO (Error Code 5)

I/O error. No such device or address.

13.1.4.12. NFS4ERR_RESTOREFH (Error Code 10030)

The RESTOREFH operation does not have a saved filehandle (identified by SAVEFH) to operate upon.

13.1.4.13. NFS4ERR_ROFS (Error Code 30)

Indicates a read-only file system. A modifying operation was attempted on a read-only file system.

13.1.4.14. NFS4ERR_XDEV (Error Code 18)

Indicates an attempt to do an operation, such as linking, that inappropriately crosses a boundary. This may be due to such boundaries as:

- That between file systems (where the fsids are different).
- That between different named attribute directories or between a named attribute directory and an ordinary directory.
- That between regions of a file system that the file system implementation treats as separate (for example for space accounting purposes), and where cross-connection between the regions are not allowed.

13.1.5. State Management Errors

These errors indicate problems with the stateid (or one of the stateids) passed to a given operation. This includes situations in which the stateid is invalid as well as situations in which the stateid is valid but designates revoked locking state. Depending on the operation, the stateid when valid may designate opens, byte-range locks, or file delegations.

13.1.5.1. NFS4ERR_ADMIN_REVOKED (Error Code 10047)

A stateid designates locking state of any type that has been revoked due to administrative interaction, possibly while the lease is valid, or because a delegation was revoked because of failure to return it, while the lease was valid.

13.1.5.2. NFS4ERR_BAD_STATEID (Error Code 10026)

A stateid generated by the current server instance was used which either:

- Does not designate any locking state (either current or superseded) for a current (state-owner, file) pair.
- Designates locking state that was freed after lease expiration but without any lease cancelation, as may happen in the handling of "courtesy locks".

13.1.5.3. NFS4ERR_EXPIRED (Error Code 10011)

A stateid or clientid designates locking state of any type that has been revoked or released due to cancellation of the client's lease, either immediately upon lease expiration, or following a later request for a conflicting lock.

13.1.5.4. NFS4ERR_LEASE_MOVED (Error Code 10031)

A lease being renewed is associated with a file system that has been migrated to a new server.

13.1.5.5. NFS4ERR_OLD_STATEID (Error Code 10024)

A stateid is provided with a seqid value that is not the most current.

13.1.5.6. NFS4ERR_STALE_STATEID (Error Code 10023)

A stateid generated by an earlier server instance was used.

13.1.6. Security Errors

These are the various permission-related errors in NFSv4.

13.1.6.1. NFS4ERR_ACCESS (Error Code 13)

Indicates permission denied. The caller does not have the correct permission to perform the requested operation. Contrast this with

NFS4ERR_PERM (Section 13.1.6.2), which restricts itself to owner or privileged user permission failures.

13.1.6.2. NFS4ERR_PERM (Error Code 1)

Indicates requester is not the owner. The operation was not allowed because the caller is neither a privileged user (root) nor the owner of the target of the operation.

13.1.6.3. NFS4ERR_WRONGSEC (Error Code 10016)

Indicates that the security mechanism being used by the client for the operation does not match the server's security policy. The client should change the security mechanism being used and re-send the operation. SECINFO can be used to determine the appropriate mechanism.

13.1.7. Name Errors

Names in NFSv4 are UTF-8 strings. When the strings are not are of length zero, the error NFS4ERR_INVAL results. When they are not valid UTF-8 the error NFS4ERR_INVAL also results, but servers may accommodate file systems with different character formats and not return this error. Besides this, there are a number of other errors to indicate specific problems with names.

13.1.7.1. NFS4ERR_BADCHAR (Error Code 10040)

A UTF-8 string contains a character which is not supported by the server in the context in which it being used.

13.1.7.2. NFS4ERR_BADNAME (Error Code 10041)

A name string in a request consisted of valid UTF-8 characters supported by the server but the name is not supported by the server as a valid name for current operation. An example might be creating a file or directory named ".." on a server whose file system uses that name for links to parent directories.

This error should not be returned due a normalization issue in a string. When a file system keeps names in a particular normalization form, it is the server's responsibility to do the appropriate normalization, rather than rejecting the name.

13.1.7.3. NFS4ERR_NAMETOOLONG (Error Code 63)

Returned when the filename in an operation exceeds the server's implementation limit.

13.1.8. Locking Errors

This section deal with errors related to locking, both as to share reservations and byte-range locking. It does not deal with errors specific to the process of reclaiming locks. Those are dealt with in the next section.

13.1.8.1. NFS4ERR_BAD_RANGE (Error Code 10042)

The range for a LOCK, LOCKT, or LOCKU operation is not appropriate to the allowable range of offsets for the server. E.g., this error results when a server which only supports 32-bit ranges receives a range that cannot be handled by that server. (See Section 15.12.4).

13.1.8.2. NFS4ERR_BAD_SEQID (Error Code 10026)

The sequence number (seqid) in a locking request is neither the next expected number or the last number processed.

13.1.8.3. NFS4ERR_DEADLOCK (Error Code 10045)

The server has been able to determine a file locking deadlock condition for a blocking lock request.

13.1.8.4. NFS4ERR_DENIED (Error Code 10010)

An attempt to lock a file is denied. Since this may be a temporary condition, the client is encouraged to re-send the lock request until the lock is accepted. See Section 9.4 for a discussion of the re-send.

13.1.8.5. NFS4ERR_LOCKED (Error Code 10012)

A read or write operation was attempted on a file where there was a conflict between the I/O and an existing lock:

- There is a share reservation inconsistent with the I/O being done.
- The range to be read or written intersects an existing mandatory byte range lock.

13.1.8.6. NFS4ERR_LOCKS_HELD (Error Code 10037)

An operation was prevented by the unexpected presence of locks.

13.1.8.7. NFS4ERR_LOCK_NOTSUPP (Error Code 10043)

A locking request was attempted which would require the upgrade or downgrade of a lock range already held by the owner when the server does not support atomic upgrade or downgrade of locks.

13.1.8.8. NFS4ERR_LOCK_RANGE (Error Code 10028)

A lock request is operating on a range that overlaps in part a currently held lock for the current lock owner and does not precisely match a single such lock where the server does not support this type of request, and thus does not implement POSIX locking semantics [35]. See Section 15.12.5, Section 15.13.5, and Section 15.14.5 for a discussion of how this applies to LOCK, LOCKT, and LOCKU respectively.

13.1.8.9. NFS4ERR_OPENMODE (Error Code 10038)

The client attempted a READ, WRITE, LOCK or other operation not sanctioned by the stateid passed (e.g., writing to a file opened only for read).

13.1.9. Reclaim Errors

These errors relate to the process of reclaiming locks after a server restart.

13.1.9.1. NFS4ERR_GRACE (Error Code 10013)

The server is in its recovery or grace period which should at least match the lease period of the server. A locking request other than a reclaim could not be granted during that period.

13.1.9.2. NFS4ERR_NO_GRACE (Error Code 10033)

The server cannot guarantee that it has not granted state to another client which may conflict with this client's state. No further reclaims from this client will succeed.

13.1.9.3. NFS4ERR_RECLAIM_BAD (Error Code 10034)

The server cannot guarantee that it has not granted state to another client which may conflict with the requested state. However, this applies only to the state requested in this call; further reclaims may succeed.

Unlike NFS4ERR_RECLAIM_CONFLICT, this can occur between correctly functioning clients and servers: the "edge condition" scenarios

described in Section 9.6.3.1 leave only the server knowing whether the client's locks are still valid, and NFS4ERR_RECLAIM_BAD is the server's way of informing the client that they are not.

13.1.9.4. NFS4ERR_RECLAIM_CONFLICT (Error Code 10035)

The reclaim attempted by the client conflicts with a lock already held by another client. Unlike NFS4ERR_RECLAIM_BAD, this can only occur if one of the clients misbehaved.

13.1.10. Client Management Errors

This sections deals with errors associated with requests used to create and manage client IDs.

13.1.10.1. NFS4ERR_CLID_INUSE (Error Code 10017)

The SETCLIENTID operation has found that a client id is already in use by another client.

13.1.10.2. NFS4ERR_STALE_CLIENTID (Error Code 10022)

A client ID not recognized by the server was used in a locking or SETCLIENTID_CONFIRM request.

13.1.11. Attribute Handling Errors

This section deals with errors specific to attribute handling within NFSv4.

13.1.11.1. NFS4ERR_ATTRNOTSUPP (Error Code 10032)

An attribute specified is not supported by the server. This error MUST NOT be returned by the GETATTR operation.

13.1.11.2. NFS4ERR_BADOWNER (Error Code 10039)

Returned when an owner or owner_group attribute value or the who field of an ace within an ACL attribute value cannot be translated to a local representation.

13.1.11.3. NFS4ERR_NOT_SAME (Error Code 10027)

This error is returned by the VERIFY operation to signify that the attributes compared were not the same as those provided in the client's request.

13.1.11.4. NFS4ERR_SAME (Error Code 10009)

This error is returned by the NVERIFY operation to signify that the attributes compared were the same as those provided in the client's request.

13.2. Operations and their valid errors

This section contains a table which gives the valid error returns for each protocol operation. The error code NFS4_OK (indicating no error) is not listed but should be understood to be returnable by all operations except ILLEGAL.

Valid error returns for each protocol operation

Operation	Errors
ACCESS	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
CLOSE	NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKS_HELD, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_OLD_STATEID, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
COMMIT	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_SYMLINK

CREATE	NFS4ERR_ACCESS, NFS4ERR_ATTRNOTSUPP, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADOWNER, NFS4ERR_BADTYPE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXIST, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NOTDIR, NFS4ERR_PERM, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
DELEGPURGE	NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_NOTSUPP, NFS4ERR_LEASE_MOVED, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE_CLIENTID
DELEGRETURN	NFS4ERR_ADMIN_REVOKED, NFS4ERR_BAD_STATEID, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_EXPIRED, NFS4ERR_INVAL, NFS4ERR_LEASE_MOVED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTSUPP, NFS4ERR_OLD_STATEID, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
GETATTR	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
GETFH	NFS4ERR_BADHANDLE, NFS4ERR_FHEXPIRED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
ILLEGAL	NFS4ERR_BADXDR, NFS4ERR_OP_ILLEGAL
LINK	NFS4ERR_ACCESS, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXIST, NFS4ERR_FHEXPIRED, NFS4ERR_FILE_OPEN, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_MLINK, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NOTDIR, NFS4ERR_NOTSUPP, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_WRONGSEC, NFS4ERR_XDEV

LOCK	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BAD_RANGE, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_BADXDR, NFS4ERR_DEADLOCK, NFS4ERR_DELAY, NFS4ERR_DENIED, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCK_NOTSUPP, NFS4ERR_LOCK_RANGE, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NO_GRACE, NFS4ERR_OLD_STATEID, NFS4ERR_OPENMODE, NFS4ERR_RECLAIM_BAD, NFS4ERR_RECLAIM_CONFLICT, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_CLIENTID, NFS4ERR_STALE_STATEID
LOCKT	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BAD_RANGE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_DENIED, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCK_RANGE, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_CLIENTID
LOCKU	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BAD_RANGE, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCK_RANGE, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_OLD_STATEID, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
LOOKUP	NFS4ERR_ACCESS, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTDIR, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_SYMLINK, NFS4ERR_WRONGSEC

LOOKUPP	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTDIR, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_SYMLINK, NFS4ERR_WRONGSEC
NVERIFY	NFS4ERR_ACCESS, NFS4ERR_ATTRNOTSUPP, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_SAME, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
OPEN	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_ATTRNOTSUPP, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADOWNER, NFS4ERR_BADXDR, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXIST, NFS4ERR_EXPIRED, NFS4ERR_FBIG, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NOTDIR, NFS4ERR_NOTSUP, NFS4ERR_NO_GRACE, NFS4ERR_OLD_STATEID, NFS4ERR_PERM, NFS4ERR_RECLAIM_BAD, NFS4ERR_RECLAIM_CONFLICT, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_SHARE_DENIED, NFS4ERR_STALE, NFS4ERR_STALE_CLIENTID, NFS4ERR_SYMLINK, NFS4ERR_WRONGSEC
OPENATTR	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_FHEXPIRED, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NOTSUPP, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE

OPEN_CONFIRM	NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_BADXDR, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_OLD_STATEID, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
OPEN_DOWNGRADE	NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_BAD_SEQID, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKS_HELD, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_OLD_STATEID, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
PUTFH	NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_MOVED, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_WRONGSEC
PUTPUBFH	NFS4ERR_DELAY, NFS4ERR_SERVERFAULT, NFS4ERR_WRONGSEC
PUTROOTFH	NFS4ERR_DELAY, NFS4ERR_SERVERFAULT, NFS4ERR_WRONGSEC
READ	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_EXPIRED, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_OLD_STATEID, NFS4ERR_OPENMODE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID, NFS4ERR_SYMLINK
READDIR	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_BAD_COOKIE, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTDIR, NFS4ERR_NOT_SAME, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_TOOSMALL

READLINK	NFS4ERR_ACCESS, NFS4ERR_BADHANDLE, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_MOVED, NFS4ERR_NOTSUP, NFS4ERR_RESOURCE, NFS4ERR_NOFILEHANDLE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
RELEASE_LOCKOWNER	NFS4ERR_BADXDR, NFS4ERR_EXPIRED, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKS_HELD, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE_CLIENTID
REMOVE	NFS4ERR_ACCESS, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_FILE_OPEN, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTDIR, NFS4ERR_NOTEMPTY, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
RENAME	NFS4ERR_ACCESS, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXIST, NFS4ERR_FHEXPIRED, NFS4ERR_FILE_OPEN, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NOTDIR, NFS4ERR_NOTEMPTY, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_WRONGSEC, NFS4ERR_XDEV
RENEW	NFS4ERR_ACCESS, NFS4ERR_BADXDR, NFS4ERR_CB_PATH_DOWN, NFS4ERR_EXPIRED, NFS4ERR_LEASE_MOVED, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE_CLIENTID
RESTOREFH	NFS4ERR_BADHANDLE, NFS4ERR_FHEXPIRED, NFS4ERR_MOVED, NFS4ERR_RESOURCE, NFS4ERR_RESTOREFH, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_WRONGSEC
SAVEFH	NFS4ERR_BADHANDLE, NFS4ERR_FHEXPIRED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE

SECINFO	NFS4ERR_ACCESS, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADNAME, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_INVAL, NFS4ERR_MOVED, NFS4ERR_NAMETOOLONG, NFS4ERR_NOENT, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOTDIR, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE
SETATTR	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_ATTRNOTSUPP, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADOWNER, NFS4ERR_BADXDR, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXPIRED, NFS4ERR_FBIG, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_OLD_STATEID, NFS4ERR_OPENMODE, NFS4ERR_PERM, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID
SETCLIENTID	NFS4ERR_BADXDR, NFS4ERR_CLID_INUSE, NFS4ERR_DELAY, NFS4ERR_INVAL, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT
SETCLIENTID_CONFIRM	NFS4ERR_BADXDR, NFS4ERR_CLID_INUSE, NFS4ERR_DELAY, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE_CLIENTID
VERIFY	NFS4ERR_ACCESS, NFS4ERR_ATTRNOTSUPP, NFS4ERR_BADCHAR, NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOT_SAME, NFS4ERR_RESOURCE, NFS4ERR_SERVERFAULT, NFS4ERR_STALE

WRITE	NFS4ERR_ACCESS, NFS4ERR_ADMIN_REVOKED, NFS4ERR_BADXDR, NFS4ERR_BADHANDLE, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_DQUOT, NFS4ERR_EXPIRED, NFS4ERR_FBIG, NFS4ERR_FHEXPIRED, NFS4ERR_GRACE, NFS4ERR_INVAL, NFS4ERR_IO, NFS4ERR_ISDIR, NFS4ERR_LEASE_MOVED, NFS4ERR_LOCKED, NFS4ERR_MOVED, NFS4ERR_NOFILEHANDLE, NFS4ERR_NOSPC, NFS4ERR_NXIO, NFS4ERR_OLD_STATEID, NFS4ERR_OPENMODE, NFS4ERR_RESOURCE, NFS4ERR_ROFS, NFS4ERR_SERVERFAULT, NFS4ERR_STALE, NFS4ERR_STALE_STATEID, NFS4ERR_SYMLINK

Table 9

13.3. Callback operations and their valid errors

This section contains a table which gives the valid error returns for each callback operation. The error code NFS4_OK (indicating no error) is not listed but should be understood to be returnable by all callback operations with the exception of CB_ILLEGAL.

Valid error returns for each protocol callback operation

Callback Operation	Errors
CB_GETATTR	NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_DELAY, NFS4ERR_INVAL, NFS4ERR_SERVERFAULT
CB_ILLEGAL	NFS4ERR_BADXDR, NFS4ERR_OP_ILLEGAL
CB_RECALL	NFS4ERR_BADHANDLE, NFS4ERR_BADXDR, NFS4ERR_BAD_STATEID, NFS4ERR_DELAY, NFS4ERR_SERVERFAULT

Table 10

13.4. Errors and the operations that use them

Error	Operations
NFS4ERR_ACCESS	ACCESS, COMMIT, CREATE, GETATTR, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, READ, READDIR, READLINK, REMOVE, RENAME, RENEW, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_ADMIN_REVOKED	CLOSE, DELEGRETURN, LOCK, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, SETATTR, WRITE
NFS4ERR_ATTRNOTSUPP	CREATE, NVERIFY, OPEN, SETATTR, VERIFY
NFS4ERR_BADCHAR	CREATE, LINK, LOOKUP, NVERIFY, OPEN, REMOVE, RENAME, SECINFO, SETATTR, VERIFY
NFS4ERR_BADHANDLE	ACCESS, CB_GETATTR, CB_RECALL, CLOSE, COMMIT, CREATE, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, READ, READDIR, READLINK, REMOVE, RENAME, RESTOREFH, SAVEFH, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_BADNAME	CREATE, LINK, LOOKUP, OPEN, REMOVE, RENAME, SECINFO
NFS4ERR_BADOWNER	CREATE, OPEN, SETATTR
NFS4ERR_BADTYPE	CREATE
NFS4ERR_BADXDR	ACCESS, CB_GETATTR, CB_ILLEGAL, CB_RECALL, CLOSE, COMMIT, CREATE, DELEGPURGE, DELEGRETURN, GETATTR, ILLEGAL, LINK, LOCK, LOCKT, LOCKU, LOOKUP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, READ, READDIR, RELEASE_LOCKOWNER, REMOVE, RENAME, RENEW, SECINFO, SETATTR, SETCLIENTID, SETCLIENTID_CONFIRM, VERIFY, WRITE
NFS4ERR_BAD_COOKIE	READDIR
NFS4ERR_BAD_RANGE	LOCK, LOCKT, LOCKU
NFS4ERR_BAD_SEQID	CLOSE, LOCK, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE
NFS4ERR_BAD_STATEID	CB_RECALL, CLOSE, DELEGRETURN, LOCK, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, SETATTR, WRITE
NFS4ERR_CB_PATH_DOWN	RENEW
NFS4ERR_CLID_INUSE	SETCLIENTID, SETCLIENTID_CONFIRM
NFS4ERR_DEADLOCK	LOCK

NFS4ERR_DELAY	ACCESS, CB_GETATTR, CB_RECALL, CLOSE, COMMIT, CREATE, DELEGPURGE, DELEGRETURN, GETATTR, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_DOWNGRADE, PUTFH, PUTPUBFH, PUTROOTFH, READ, READDIR, READLINK, REMOVE, RENAME, SECINFO, SETATTR, SETCLIENTID, SETCLIENTID_CONFIRM, VERIFY, WRITE
NFS4ERR_DENIED	LOCK, LOCKT
NFS4ERR_DQUOT	CREATE, LINK, OPEN, OPENATTR, RENAME, SETATTR, WRITE
NFS4ERR_EXIST	CREATE, LINK, OPEN, RENAME
NFS4ERR_EXPIRED	CLOSE, DELEGRETURN, LOCK, LOCKT, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, RELEASE_LOCKOWNER, RENEW, SETATTR, WRITE
NFS4ERR_FBIG	OPEN, SETATTR, WRITE
NFS4ERR_FHEXPIRED	ACCESS, CLOSE, COMMIT, CREATE, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, READ, READDIR, READLINK, REMOVE, RENAME, RESTOREFH, SAVEFH, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_FILE_OPEN	LINK, REMOVE, RENAME
NFS4ERR_GRACE	GETATTR, LOCK, LOCKT, LOCKU, NVERIFY, OPEN, READ, REMOVE, RENAME, SETATTR, VERIFY, WRITE
NFS4ERR_INVAL	ACCESS, CB_GETATTR, CLOSE, COMMIT, CREATE, DELEGRETURN, GETATTR, LINK, LOCK, LOCKT, LOCKU, LOOKUP, NVERIFY, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, READDIR, READLINK, REMOVE, RENAME, SECINFO, SETATTR, SETCLIENTID, VERIFY, WRITE
NFS4ERR_IO	ACCESS, COMMIT, CREATE, GETATTR, LINK, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, READ, READDIR, READLINK, REMOVE, RENAME, SETATTR, VERIFY, WRITE
NFS4ERR_ISDIR	CLOSE, COMMIT, LINK, LOCK, LOCKT, LOCKU, OPEN, OPEN_CONFIRM, READ, READLINK, SETATTR, WRITE

NFS4ERR_LEASE_MOVED	CLOSE, DELEGPURGE, DELEGRETURN, LOCK, LOCKT, LOCKU, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, RELEASE_LOCKOWNER, RENEW, SETATTR, WRITE
NFS4ERR_LOCKED	READ, SETATTR, WRITE
NFS4ERR_LOCKS_HELD	CLOSE, OPEN_DOWNGRADE, RELEASE_LOCKOWNER
NFS4ERR_LOCK_NOTSUPP	LOCK
NFS4ERR_LOCK_RANGE	LOCK, LOCKT, LOCKU
NFS4ERR_MLINK	LINK
NFS4ERR_MOVED	ACCESS, CLOSE, COMMIT, CREATE, DELEGRETURN, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, READ, READDIR, READLINK, REMOVE, RENAME, RESTOREFH, SAVEFH, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_NAMETOOLONG	CREATE, LINK, LOOKUP, OPEN, REMOVE, RENAME, SECINFO
NFS4ERR_NOENT	LINK, LOOKUP, LOOKUPP, OPEN, OPENATTR, REMOVE, RENAME, SECINFO
NFS4ERR_NOFILEHANDLE	ACCESS, CLOSE, COMMIT, CREATE, DELEGRETURN, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, READDIR, READLINK, REMOVE, RENAME, SAVEFH, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_NOSPC	CREATE, LINK, OPEN, OPENATTR, RENAME, SETATTR, WRITE
NFS4ERR_NOTDIR	CREATE, LINK, LOOKUP, LOOKUPP, OPEN, READDIR, REMOVE, RENAME, SECINFO
NFS4ERR_NOTEMPTY	REMOVE, RENAME
NFS4ERR_NOTSUP	OPEN, READLINK
NFS4ERR_NOTSUPP	DELEGPURGE, DELEGRETURN, LINK, OPENATTR
NFS4ERR_NOT_SAME	READDIR, VERIFY
NFS4ERR_NO_GRACE	LOCK, OPEN
NFS4ERR_NXIO	WRITE
NFS4ERR_OLD_STATEID	CLOSE, DELEGRETURN, LOCK, LOCKU, OPEN, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, SETATTR, WRITE
NFS4ERR_OPENMODE	LOCK, READ, SETATTR, WRITE
NFS4ERR_OP_ILLEGAL	CB_ILLEGAL, ILLEGAL
NFS4ERR_PERM	CREATE, OPEN, SETATTR
NFS4ERR_RECLAIM_BAD	LOCK, OPEN

NFS4ERR_RECLAIM_CONFLICT	LOCK, OPEN
NFS4ERR_RESOURCE	ACCESS, CLOSE, COMMIT, CREATE, DELEGPURGE, DELEGRETURN, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, READDIR, READLINK, RELEASE_LOCKOWNER, REMOVE, RENAME, RENEW, RESTOREFH, SAVEFH, SECINFO, SETATTR, SETCLIENTID, SETCLIENTID_CONFIRM, VERIFY, WRITE
NFS4ERR_RESTOREFH	RESTOREFH
NFS4ERR_ROFS	COMMIT, CREATE, LINK, OPEN, OPENATTR, OPEN_DOWNGRADE, REMOVE, RENAME, SETATTR, WRITE
NFS4ERR_SAME	NVERIFY
NFS4ERR_SERVERFAULT	ACCESS, CB_GETATTR, CB_RECALL, CLOSE, COMMIT, CREATE, DELEGPURGE, DELEGRETURN, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, PUTPUBFH, PUTROOTFH, READ, READDIR, READLINK, RELEASE_LOCKOWNER, REMOVE, RENAME, RENEW, RESTOREFH, SAVEFH, SECINFO, SETATTR, SETCLIENTID, SETCLIENTID_CONFIRM, VERIFY, WRITE
NFS4ERR_SHARE_DENIED	OPEN
NFS4ERR_STALE	ACCESS, CLOSE, COMMIT, CREATE, DELEGRETURN, GETATTR, GETFH, LINK, LOCK, LOCKT, LOCKU, LOOKUP, LOOKUPP, NVERIFY, OPEN, OPENATTR, OPEN_CONFIRM, OPEN_DOWNGRADE, PUTFH, READ, READDIR, READLINK, REMOVE, RENAME, RESTOREFH, SAVEFH, SECINFO, SETATTR, VERIFY, WRITE
NFS4ERR_STALE_CLIENTID	DELEGPURGE, LOCK, LOCKT, OPEN, RELEASE_LOCKOWNER, RENEW, SETCLIENTID_CONFIRM
NFS4ERR_STALE_STATEID	CLOSE, DELEGRETURN, LOCK, LOCKU, OPEN_CONFIRM, OPEN_DOWNGRADE, READ, SETATTR, WRITE
NFS4ERR_SYMLINK	COMMIT, LOOKUP, LOOKUPP, OPEN, READ, WRITE
NFS4ERR_TOOSMALL	READDIR
NFS4ERR_WRONGSEC	LINK, LOOKUP, LOOKUPP, OPEN, PUTFH, PUTPUBFH, PUTROOTFH, RENAME, RESTOREFH
NFS4ERR_XDEV	LINK, RENAME

Table 11

14. NFSv4 Requests

For the NFSv4 RPC program, there are two traditional RPC procedures: NULL and COMPOUND. All other functionality is defined as a set of operations and these operations are defined in normal XDR/RPC syntax and semantics. However, these operations are encapsulated within the COMPOUND procedure. This requires that the client combine one or more of the NFSv4 operations into a single request.

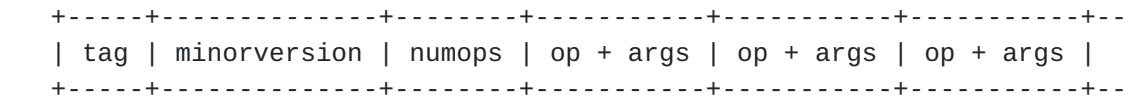
The NFS4_CALLBACK program is used to provide server to client signaling and is constructed in a similar fashion as the NFSv4 program. The procedures CB_NULL and CB_COMPOUND are defined in the same way as NULL and COMPOUND are within the NFS program. The CB_COMPOUND request also encapsulates the remaining operations of the NFS4_CALLBACK program. There is no predefined RPC program number for the NFS4_CALLBACK program. It is up to the client to specify a program number in the "transient" program range. The program and port number of the NFS4_CALLBACK program are provided by the client as part of the SETCLIENTID/SETCLIENTID_CONFIRM sequence. The program and port can be changed by another SETCLIENTID/SETCLIENTID_CONFIRM sequence, and it is possible to use the sequence to change them within a client incarnation without removing relevant leased client state.

14.1. Compound Procedure

The COMPOUND procedure provides the opportunity for better performance within high latency networks. The client can avoid cumulative latency of multiple RPCs by combining multiple dependent operations into a single COMPOUND procedure. A compound operation may provide for protocol simplification by allowing the client to combine basic procedures into a single request that is customized for the client's environment.

The CB_COMPOUND procedure precisely parallels the features of COMPOUND as described above.

The basic structure of the COMPOUND procedure is:



and the reply's structure is:

```
+------------+-----+--------+-----------------------+--
|last status | tag | numres | status + op + results |
+------------+-----+--------+-----------------------+--
```

The numops and numres fields, used in the depiction above, represent the count for the counted array encoding use to signify the number of arguments or results encoded in the request and response. As per the XDR encoding, these counts must match exactly the number of operation arguments or results encoded.

14.2. Evaluation of a Compound Request

The server will process the COMPOUND procedure by evaluating each of the operations within the COMPOUND procedure in order. Each component operation consists of a 32 bit operation code, followed by the argument of length determined by the type of operation. The results of each operation are encoded in sequence into a reply buffer. The results of each operation are preceded by the opcode and a status code (normally zero). If an operation results in a non-zero status code, the status will be encoded and evaluation of the compound sequence will halt and the reply will be returned. Note that evaluation stops even in the event of "non error" conditions such as NFS4ERR_SAME.

There are no atomicity requirements for the operations contained within the COMPOUND procedure. The operations being evaluated as part of a COMPOUND request may be evaluated simultaneously with other COMPOUND requests that the server receives.

It is the client's responsibility for recovering from any partially completed COMPOUND procedure. Partially completed COMPOUND procedures may occur at any point due to errors such as NFS4ERR_RESOURCE and NFS4ERR_DELAY. This may occur even given an otherwise valid operation string. Further, a server reboot which occurs in the middle of processing a COMPOUND procedure may leave the client with the difficult task of determining how far COMPOUND processing has proceeded. Therefore, the client should avoid overly complex COMPOUND procedures in the event of the failure of an operation within the procedure.

Each operation assumes a "current" and "saved" filehandle that is available as part of the execution context of the compound request. Operations may set, change, or return the current filehandle. The "saved" filehandle is used for temporary storage of a filehandle value and as operands for the RENAME and LINK operations.

14.3. Synchronous Modifying Operations

NFSv4 operations that modify the filesystem are synchronous. When an operation is successfully completed at the server, the client can depend that any data associated with the request is now on stable storage (the one exception is in the case of the file data in a WRITE operation with the UNSTABLE option specified).

This implies that any previous operations within the same compound request are also reflected in stable storage. This behavior enables the client's ability to recover from a partially executed compound request which may resulted from the failure of the server. For example, if a compound request contains operations A and B and the server is unable to send a response to the client, depending on the progress the server made in servicing the request the result of both operations may be reflected in stable storage or just operation A may be reflected. The server must not have just the results of operation B in stable storage.

14.4. Operation Values

The operations encoded in the COMPOUND procedure are identified by operation values. To avoid overlap with the RPC procedure numbers, operations 0 (zero) and 1 are not defined. Operation 2 is not defined but reserved for future use with minor versioning.

15. NFSv4 Procedures

15.1. Procedure 0: NULL - No Operation

15.1.1. SYNOPSIS

<null>

15.1.2. ARGUMENT

void;

15.1.3. RESULT

void;

15.1.4. DESCRIPTION

Standard NULL procedure. Void argument, void response. This procedure has no functionality associated with it. Because of this it is sometimes used to measure the overhead of processing a service

request. Therefore, the server should ensure that no unnecessary work is done in servicing this procedure.

15.2. Procedure 1: COMPOUND - Compound Operations

15.2.1. SYNOPSIS

```
compoundargs -> compoundres
```

15.2.2. ARGUMENT

```
union nfs_argop4 switch (nfs_opnum4 argop) {
        case <OPCODE>: <argument>;
        ...
};


struct COMPOUND4args {
        comptag4        tag;
        uint32_t        minorversion;
        nfs_argop4      argarray<>;
};
```

15.2.3. RESULT

```
union nfs_resop4 switch (nfs_opnum4 resop) {
        case <OPCODE>: <argument>;
        ...
};


struct COMPOUND4res {
        nfsstat4        status;
        comptag4        tag;
        nfs_resop4      resarray<>;
};
```

15.2.4. DESCRIPTION

The COMPOUND procedure is used to combine one or more of the NFS operations into a single RPC request. The main NFS RPC program has two main procedures: NULL and COMPOUND. All other operations use the COMPOUND procedure as a wrapper.

The COMPOUND procedure is used to combine individual operations into a single RPC request. The server interprets each of the operations in turn. If an operation is executed by the server and the status of that operation is NFS4_OK, then the next operation in the COMPOUND

procedure is executed. The server continues this process until there are no more operations to be executed or one of the operations has a status value other than NFS4_OK.

In the processing of the COMPOUND procedure, the server may find that it does not have the available resources to execute any or all of the operations within the COMPOUND sequence. In this case, the error NFS4ERR_RESOURCE will be returned for the particular operation within the COMPOUND procedure where the resource exhaustion occurred. This assumes that all previous operations within the COMPOUND sequence have been evaluated successfully. The results for all of the evaluated operations must be returned to the client.

The server will generally choose between two methods of decoding the client's request. The first would be the traditional one-pass XDR decode, in which decoding of the entire COMPOUND precedes execution of any operation within it. If there is an XDR decoding error in this case, an RPC XDR decode error would be returned. The second method would be to make an initial pass to decode the basic COMPOUND request and then to XDR decode each of the individual operations, as the server is ready to execute it. In this case, the server may encounter an XDR decode error during such an operation decode, after previous operations within the COMPOUND have been executed. In this case, the server would return the error NFS4ERR_BADXDR to signify the decode error.

The COMPOUND arguments contain a "minorversion" field. The initial and default value for this field is 0 (zero). This field will be used by future minor versions such that the client can communicate to the server what minor version is being requested. If the server receives a COMPOUND procedure with a minorversion field value that it does not support, the server MUST return an error of NFS4ERR_MINOR_VERS_MISMATCH and a zero length resultdata array.

Contained within the COMPOUND results is a "status" field. If the results array length is non-zero, this status must be equivalent to the status of the last operation that was executed within the COMPOUND procedure. Therefore, if an operation incurred an error then the "status" value will be the same error value as is being returned for the operation that failed.

Note that operations, 0 (zero) and 1 (one) are not defined for the COMPOUND procedure. Operation 2 is not defined but reserved for future definition and use with minor versioning. If the server receives a operation array that contains operation 2 and the minorversion field has a value of 0 (zero), an error of NFS4ERR_OP_ILLEGAL, as described in the next paragraph, is returned to the client. If an operation array contains an operation 2 and the

minorversion field is non-zero and the server does not support the minor version, the server returns an error of NFS4ERR_MINOR_VERS_MISMATCH. Therefore, the NFS4ERR_MINOR_VERS_MISMATCH error takes precedence over all other errors.

It is possible that the server receives a request that contains an operation that is less than the first legal operation (OP_ACCESS) or greater than the last legal operation (OP_RELEASE_LOCKOWNER). In this case, the server's response will encode the opcode OP_ILLEGAL rather than the illegal opcode of the request. The status field in the ILLEGAL return results will set to NFS4ERR_OP_ILLEGAL. The COMPOUND procedure's return results will also be NFS4ERR_OP_ILLEGAL.

The definition of the "tag" in the request is left to the implementor. It may be used to summarize the content of the compound request for the benefit of packet sniffers and engineers debugging implementations. However, the value of "tag" in the response SHOULD be the same value as provided in the request. This applies to the tag field of the CB_COMPOUND procedure as well.

15.2.4.1. Current Filehandle

The current and saved filehandle are used throughout the protocol. Most operations implicitly use the current filehandle as a argument and many set the current filehandle as part of the results. The combination of client specified sequences of operations and current and saved filehandle arguments and results allows for greater protocol flexibility. The best or easiest example of current filehandle usage is a sequence like the following:

```
PUTFH fh1              {fh1}
LOOKUP "compA"         {fh2}
GETATTR                {fh2}
LOOKUP "compB"         {fh3}
GETATTR                {fh3}
LOOKUP "compC"         {fh4}
GETATTR                {fh4}
GETFH
```

Figure 1

In this example, the PUTFH (Section 15.22) operation explicitly sets the current filehandle value while the result of each LOOKUP operation sets the current filehandle value to the resultant file system object. Also, the client is able to insert GETATTR operations using the current filehandle as an argument.

The PUTROOTFH (Section 15.24) and PUTPUBFH (Section 15.24) operations also set the current filehandle. The above example would replace "PUTFH fh1" with PUTROOTFH or PUTPUBFH with no filehandle argument in order to achieve the same effect (on the assumption that "compA" is directly below the root of the namespace).

Along with the current filehandle, there is a saved filehandle. While the current filehandle is set as the result of operations like LOOKUP, the saved filehandle must be set directly with the use of the SAVEFH operation. The SAVEFH operations copies the current filehandle value to the saved value. The saved filehandle value is used in combination with the current filehandle value for the LINK and RENAME operations. The RESTOREFH operation will copy the saved filehandle value to the current filehandle value; as a result, the saved filehandle value may be used a sort of "scratch" area for the client's series of operations.

15.2.5. IMPLEMENTATION

Since an error of any type may occur after only a portion of the operations have been evaluated, the client must be prepared to recover from any failure. If the source of an NFS4ERR_RESOURCE error was a complex or lengthy set of operations, it is likely that if the number of operations were reduced the server would be able to evaluate them successfully. Therefore, the client is responsible for dealing with this type of complexity in recovery.

The client SHOULD NOT construct a COMPOUND which mixes operations for different client IDs.

15.3. Operation 3: ACCESS - Check Access Rights

15.3.1. SYNOPSIS

(cfh), accessreq -> supported, accessrights

15.3.2. ARGUMENT

```
const ACCESS4_READ      = 0x00000001;
const ACCESS4_LOOKUP    = 0x00000002;
const ACCESS4_MODIFY    = 0x00000004;
const ACCESS4_EXTEND    = 0x00000008;
const ACCESS4_DELETE    = 0x00000010;
const ACCESS4_EXECUTE   = 0x00000020;

struct ACCESS4args {
        /* CURRENT_FH: object */
        uint32_t        access;
};
```

15.3.3. RESULT

```
struct ACCESS4resok {
        uint32_t        supported;
        uint32_t        access;
};

union ACCESS4res switch (nfsstat4 status) {
 case NFS4_OK:
         ACCESS4resok   resok4;
 default:
         void;
};
```

15.3.4. DESCRIPTION

ACCESS determines the access rights that a user, as identified by the credentials in the RPC request, has with respect to the file system object specified by the current filehandle. The client encodes the set of access rights that are to be checked in the bit mask "access". The server checks the permissions encoded in the bit mask. If a status of NFS4_OK is returned, two bit masks are included in the response. The first, "supported", represents the access rights for which the server can verify reliably. The second, "access", represents the access rights available to the user for the filehandle provided. On success, the current filehandle retains its value.

Note that the supported field will contain only as many values as were originally sent in the arguments. For example, if the client sends an ACCESS operation with only the ACCESS4_READ value set and the server supports this value, the server will return only

ACCESS4_READ even if it could have reliably checked other values.

The results of this operation are necessarily advisory in nature. A return status of NFS4_OK and the appropriate bit set in the bit mask does not imply that such access will be allowed to the file system object in the future. This is because access rights can be revoked by the server at any time.

The following access permissions may be requested:

ACCESS4_READ: Read data from file or read a directory.

ACCESS4_LOOKUP: Look up a name in a directory (no meaning for non-directory objects).

ACCESS4_MODIFY: Rewrite existing file data or modify existing directory entries.

ACCESS4_EXTEND: Write new data or add directory entries.

ACCESS4_DELETE: Delete an existing directory entry.

ACCESS4_EXECUTE: Execute file (no meaning for a directory).

On success, the current filehandle retains its value.

15.3.5. IMPLEMENTATION

In general, it is not sufficient for the client to attempt to deduce access permissions by inspecting the uid, gid, and mode fields in the file attributes or by attempting to interpret the contents of the ACL attribute. This is because the server may perform uid or gid mapping or enforce additional access control restrictions. It is also possible that the server may not be in the same ID space as the client. In these cases (and perhaps others), the client cannot reliably perform an access check with only current file attributes.

In the NFSv2 protocol, the only reliable way to determine whether an operation was allowed was to try it and see if it succeeded or failed. Using the ACCESS operation in the NFSv4 protocol, the client can ask the server to indicate whether or not one or more classes of operations are permitted. The ACCESS operation is provided to allow clients to check before doing a series of operations which will result in an access failure. The OPEN operation provides a point where the server can verify access to the file object and method to return that information to the client. The ACCESS operation is still useful for directory operations or for use in the case the UNIX API "access" is used on the client.

The information returned by the server in response to an ACCESS call is not permanent. It was correct at the exact time that the server performed the checks, but not necessarily afterward. The server can revoke access permission at any time.

The client should use the effective credentials of the user to build the authentication information in the ACCESS request used to determine access rights. It is the effective user and group credentials that are used in subsequent read and write operations.

Many implementations do not directly support the ACCESS4_DELETE permission. Operating systems like UNIX will ignore the ACCESS4_DELETE bit if set on an access request on a non-directory object. In these systems, delete permission on a file is determined by the access permissions on the directory in which the file resides, instead of being determined by the permissions of the file itself. Therefore, the mask returned enumerating which access rights can be determined will have the ACCESS4_DELETE value set to 0. This indicates to the client that the server was unable to check that particular access right. The ACCESS4_DELETE bit in the access mask returned will then be ignored by the client.

15.4. Operation 4: CLOSE - Close File

15.4.1. SYNOPSIS

(cfh), seqid, open_stateid -> open_stateid

15.4.2. ARGUMENT

```
struct CLOSE4args {
        /* CURRENT_FH: object */
        seqid4          seqid;
        stateid4        open_stateid;
};
```

15.4.3. RESULT

```
union CLOSE4res switch (nfsstat4 status) {
 case NFS4_OK:
         stateid4       open_stateid;
 default:
         void;
};
```

15.4.4. DESCRIPTION

The CLOSE operation releases share reservations for the regular or named attribute file as specified by the current filehandle. The share reservations and other state information released at the server as a result of this CLOSE is only associated with the supplied stateid. The sequence id provides for the correct ordering. State associated with other OPENs is not affected.

If byte-range locks are held, the client SHOULD release all locks before issuing a CLOSE. The server MAY free all outstanding locks on CLOSE but some servers may not support the CLOSE of a file that still has byte-range locks held. The server MUST return failure if any locks would exist after the CLOSE.

On success, the current filehandle retains its value.

15.4.5. IMPLEMENTATION

Even though CLOSE returns a stateid, this stateid is not useful to the client and should be treated as deprecated. CLOSE "shuts down" the state associated with all OPENs for the file by a single open-owner. As noted above, CLOSE will either release all file locking state or return an error. Therefore, the stateid returned by CLOSE is not useful for operations that follow.

15.5. Operation 5: COMMIT - Commit Cached Data

15.5.1. SYNOPSIS

```
(cfh), offset, count -> verifier
```

15.5.2. ARGUMENT

```
struct COMMIT4args {
        /* CURRENT_FH: file */
        offset4         offset;
        count4          count;
};
```

15.5.3. RESULT

```
struct COMMIT4resok {
        verifier4       writeverf;
};

union COMMIT4res switch (nfsstat4 status) {
 case NFS4_OK:
         COMMIT4resok   resok4;
 default:
         void;
};
```

15.5.4. DESCRIPTION

The COMMIT operation forces or flushes data to stable storage for the file specified by the current filehandle. The flushed data is that which was previously written with a WRITE operation which had the stable field set to UNSTABLE4.

The offset specifies the position within the file where the flush is to begin. An offset value of 0 (zero) means to flush data starting at the beginning of the file. The count specifies the number of bytes of data to flush. If count is 0 (zero), a flush from offset to the end of the file is done.

The server returns a write verifier upon successful completion of the COMMIT. The write verifier is used by the client to determine if the server has restarted or rebooted between the initial WRITE(s) and the COMMIT. The client does this by comparing the write verifier returned from the initial writes and the verifier returned by the COMMIT operation. The server must vary the value of the write verifier at each server event or instantiation that may lead to a loss of uncommitted data. Most commonly this occurs when the server is rebooted; however, other events at the server may result in uncommitted data loss as well.

On success, the current filehandle retains its value.

15.5.5. IMPLEMENTATION

The COMMIT operation is similar in operation and semantics to the POSIX fsync() [36] system call that synchronizes a file's state with the disk (file data and metadata is flushed to disk or stable storage). COMMIT performs the same operation for a client, flushing any unsynchronized data and metadata on the server to the server's disk or stable storage for the specified file. Like fsync(), it may

be that there is some modified data or no modified data to synchronize. The data may have been synchronized by the server's normal periodic buffer synchronization activity. COMMIT should return NFS4_OK, unless there has been an unexpected error.

COMMIT differs from fsync() in that it is possible for the client to flush a range of the file (most likely triggered by a buffer-reclamation scheme on the client before file has been completely written).

The server implementation of COMMIT is reasonably simple. If the server receives a full file COMMIT request, that is starting at offset 0 and count 0, it should do the equivalent of fsync()'ing the file. Otherwise, it should arrange to have the cached data in the range specified by offset and count to be flushed to stable storage. In both cases, any metadata associated with the file must be flushed to stable storage before returning. It is not an error for there to be nothing to flush on the server. This means that the data and metadata that needed to be flushed have already been flushed or lost during the last server failure.

The client implementation of COMMIT is a little more complex. There are two reasons for wanting to commit a client buffer to stable storage. The first is that the client wants to reuse a buffer. In this case, the offset and count of the buffer are sent to the server in the COMMIT request. The server then flushes any cached data based on the offset and count, and flushes any metadata associated with the file. It then returns the status of the flush and the write verifier. The other reason for the client to generate a COMMIT is for a full file flush, such as may be done at close. In this case, the client would gather all of the buffers for this file that contain uncommitted data, do the COMMIT operation with an offset of 0 and count of 0, and then free all of those buffers. Any other dirty buffers would be sent to the server in the normal fashion.

After a buffer is written by the client with the stable parameter set to UNSTABLE4, the buffer must be considered as modified by the client until the buffer has either been flushed via a COMMIT operation or written via a WRITE operation with stable parameter set to FILE_SYNC4 or DATA_SYNC4. This is done to prevent the buffer from being freed and reused before the data can be flushed to stable storage on the server.

When a response is returned from either a WRITE or a COMMIT operation and it contains a write verifier that is different than previously returned by the server, the client will need to retransmit all of the buffers containing uncommitted cached data to the server. How this is to be done is up to the implementor. If there is only one buffer

of interest, then it should probably be sent back over in a WRITE request with the appropriate stable parameter. If there is more than one buffer, it might be worthwhile retransmitting all of the buffers in WRITE requests with the stable parameter set to UNSTABLE4 and then retransmitting the COMMIT operation to flush all of the data on the server to stable storage. The timing of these retransmissions is left to the implementor.

The above description applies to page-cache-based systems as well as buffer-cache-based systems. In those systems, the virtual memory system will need to be modified instead of the buffer cache.

15.6. Operation 6: CREATE - Create a Non-Regular File Object

15.6.1. SYNOPSIS

(cfh), name, type, attrs -> (cfh), cinfo, attrset

15.6.2. ARGUMENT

```
union createtype4 switch (nfs_ftype4 type) {
 case NF4LNK:
        linktext4 linkdata;
 case NF4BLK:
 case NF4CHR:
        specdata4 devdata;
 case NF4SOCK:
 case NF4FIFO:
 case NF4DIR:
        void;
 default:
        void;  /* server should return NFS4ERR_BADTYPE */
};

struct CREATE4args {
        /* CURRENT_FH: directory for creation */
        createtype4     objtype;
        component4      objname;
        fattr4          createattrs;
};
```

15.6.3. RESULT

```
struct CREATE4resok {
        change_info4    cinfo;
        bitmap4         attrset;        /* attributes set */
};

union CREATE4res switch (nfsstat4 status) {
 case NFS4_OK:
         CREATE4resok resok4;
 default:
         void;
};
```

15.6.4. DESCRIPTION

The CREATE operation creates a non-regular file object in a directory with a given name. The OPEN operation MUST be used to create a regular file.

The objname specifies the name for the new object. The objtype determines the type of object to be created: directory, symlink, etc.

If an object of the same name already exists in the directory, the server will return the error NFS4ERR_EXIST.

For the directory where the new file object was created, the server returns change_info4 information in cinfo. With the atomic field of the change_info4 struct, the server will indicate if the before and after change attributes were obtained atomically with respect to the file object creation.

If the objname is of zero length, NFS4ERR_INVAL will be returned. The objname is also subject to the normal UTF-8, character support, and name checks. See Section 12.3 for further discussion.

If the objname has a length of 0 (zero), or if objname does not obey the UTF-8 definition, the error NFS4ERR_INVAL will be returned.

The current filehandle is replaced by that of the new object.

The createattrs specifies the initial set of attributes for the object. The set of attributes may include any writable attribute valid for the object type. When the operation is successful, the server will return to the client an attribute mask signifying which attributes were successfully set for the object.

If createattrs includes neither the owner attribute nor an ACL with an ACE for the owner, and if the server's filesystem both supports and requires an owner attribute (or an owner ACE) then the server MUST derive the owner (or the owner ACE). This would typically be from the principal indicated in the RPC credentials of the call, but the server's operating environment or filesystem semantics may dictate other methods of derivation. Similarly, if createattrs includes neither the group attribute nor a group ACE, and if the server's filesystem both supports and requires the notion of a group attribute (or group ACE), the server MUST derive the group attribute (or the corresponding owner ACE) for the file. This could be from the RPC call's credentials, such as the group principal if the credentials include it (such as with AUTH_SYS), from the group identifier associated with the principal in the credentials (e.g., POSIX systems have a user database [37] that has the group identifier for every user identifier), inherited from directory the object is created in, or whatever else the server's operating environment or filesystem semantics dictate. This applies to the OPEN operation too.

Conversely, it is possible the client will specify in createattrs an owner attribute or group attribute or ACL that the principal indicated the RPC call's credentials does not have permissions to create files for. The error to be returned in this instance is NFS4ERR_PERM. This applies to the OPEN operation too.

15.6.5. IMPLEMENTATION

If the client desires to set attribute values after the create, a SETATTR operation can be added to the COMPOUND request so that the appropriate attributes will be set.

15.7. Operation 7: DELEGPURGE - Purge Delegations Awaiting Recovery

15.7.1. SYNOPSIS

```
clientid ->
```

15.7.2. ARGUMENT

```
struct DELEGPURGE4args {
        clientid4       clientid;
};
```

15.7.3. RESULT

```
struct DELEGPURGE4res {
        nfsstat4        status;
};
```

15.7.4. DESCRIPTION

Purges all of the delegations awaiting recovery for a given client. This is useful for clients which do not commit delegation information to stable storage to indicate that conflicting requests need not be delayed by the server awaiting recovery of delegation information.

This operation in provided to support clients that record delegation information on stable storage on the client. In this case, DELEGPURGE should be issued immediately after doing delegation recovery (using CLAIM_DELEGATE_PREV) on all delegations known to the client. Doing so will notify the server that no additional delegations for the client will be recovered allowing it to free resources, and avoid delaying other clients who make requests that conflict with the unrecovered delegations. All client SHOULD use DELEGPURGE as part of recovery once it is known that no further CLAIM_DELEGATE_PREV recovery will be done. This includes clients that do not record delegation information on stable storage, who would then do a DELEGPURGE immediately after SETCLIENTID_CONFIRM.

The set of delegations known to the server and the client may be different. The reasons for this include:

- A client may fail after making a request which resulted in delegation but before it received the results and committed them to the client's stable storage.

- A client may fail after deleting its indication that a delegation exists but before the delegation return is fully processed by the server.

- In the case in which the server and the client restart, the server may have limited persistent recording of delegation to a subset of those in existence.

- A client may have only persistently recorded information about a subset of delegations.

The server MAY support DELEGPURGE, but its support or non-support should match that of CLAIM_DELEGATE_PREV:

- A server may support both DELEGPURGE and CLAIM_DELEGATE_PREV.

- A server may support neither DELEGPURGE nor CLAIM_DELEGATE_PREV.

This fact allows a client starting up to determine if the server is prepared to support persistent storage of delegation information and thus whether it may use write-back caching to local persistent storage, relying on CLAIM_DELEGATE_PREV recovery to allow such changed data to be flushed safely to the server in the event of client restart.

15.8. Operation 8: DELEGRETURN - Return Delegation

15.8.1. SYNOPSIS

(cfh), stateid ->

15.8.2. ARGUMENT

```
struct DELEGRETURN4args {
        /* CURRENT_FH: delegated file */
        stateid4        deleg_stateid;
};
```

15.8.3. RESULT

```
struct DELEGRETURN4res {
        nfsstat4        status;
};
```

15.8.4. DESCRIPTION

Returns the delegation represented by the current filehandle and stateid.

Delegations may be returned when recalled or voluntarily (i.e., before the server has recalled them). In either case the client must properly propagate state changed under the context of the delegation to the server before returning the delegation.

15.9. Operation 9: GETATTR - Get Attributes

15.9.1. SYNOPSIS

(cfh), attrbits -> attrbits, attrvals

15.9.2. ARGUMENT

```
struct GETATTR4args {
        /* CURRENT_FH: directory or file */
        bitmap4         attr_request;
};
```

15.9.3. RESULT

```
struct GETATTR4resok {
        fattr4          obj_attributes;
};

union GETATTR4res switch (nfsstat4 status) {
 case NFS4_OK:
         GETATTR4resok  resok4;
 default:
         void;
};
```

15.9.4. DESCRIPTION

The GETATTR operation will obtain attributes for the filesystem object specified by the current filehandle. The client sets a bit in the bitmap argument for each attribute value that it would like the server to return. The server returns an attribute bitmap that indicates the attribute values for which it was able to return, followed by the attribute values ordered lowest attribute number first.

The server MUST return a value for each attribute that the client requests if the attribute is supported by the server. If the server does not support an attribute or cannot approximate a useful value then it MUST NOT return the attribute value and MUST NOT set the attribute bit in the result bitmap. The server MUST return an error if it supports an attribute on the target but cannot obtain its value. In that case no attribute values will be returned.

File systems which are absent should be treated as having support for a very small set of attributes as described in GETATTR Within an Absent File System (Section 7.3.1), even if previously, when the file system was present, more attributes were supported.

All servers MUST support the REQUIRED attributes as specified in the section File Attributes (Section 5), for all file systems, with the exception of absent file systems.

On success, the current filehandle retains its value.

15.9.5. IMPLEMENTATION

Suppose there is a OPEN_DELEGATE_WRITE delegation held by another client for file in question and size and/or change are among the set of attributes being interrogated. The server has two choices. First, the server can obtain the actual current value of these attributes from the client holding the delegation by using the CB_GETATTR callback. Second, the server, particularly when the delegated client is unresponsive, can recall the delegation in question. The GETATTR MUST NOT proceed until one of the following occurs:

- The requested attribute values are returned in the response to CB_GETATTR.
- The OPEN_DELEGATE_WRITE delegation is returned.
- The OPEN_DELEGATE_WRITE delegation is revoked.

Unless one of the above happens very quickly, one or more NFS4ERR_DELAY errors will be returned if while a delegation is outstanding.

15.10. Operation 10: GETFH - Get Current Filehandle

15.10.1. SYNOPSIS

```
(cfh) -> filehandle
```

15.10.2. ARGUMENT

```
/* CURRENT_FH: */
void;
```

15.10.3. RESULT

```
struct GETFH4resok {
        nfs_fh4         object;
};

union GETFH4res switch (nfsstat4 status) {
 case NFS4_OK:
        GETFH4resok     resok4;
 default:
        void;
};
```

15.10.4. DESCRIPTION

This operation returns the current filehandle value.

On success, the current filehandle retains its value.

15.10.5. IMPLEMENTATION

Operations that change the current filehandle like LOOKUP or CREATE do not automatically return the new filehandle as a result. For instance, if a client needs to lookup a directory entry and obtain its filehandle then the following request is needed.

```
  PUTFH  (directory filehandle)
  LOOKUP (entry name)
  GETFH
```

15.11. Operation 11: LINK - Create Link to a File

15.11.1. SYNOPSIS

```
  (sfh), (cfh), newname -> (cfh), cinfo
```

15.11.2. ARGUMENT

```
struct LINK4args {
        /* SAVED_FH: source object */
        /* CURRENT_FH: target directory */
        component4      newname;
};
```

15.11.3. RESULT

```
struct LINK4resok {
        change_info4    cinfo;
};

union LINK4res switch (nfsstat4 status) {
 case NFS4_OK:
         LINK4resok resok4;
 default:
         void;
};
```

15.11.4. DESCRIPTION

The LINK operation creates an additional newname for the file represented by the saved filehandle, as set by the SAVEFH operation, in the directory represented by the current filehandle. The existing file and the target directory must reside within the same filesystem on the server. On success, the current filehandle will continue to be the target directory. If an object exists in the target directory with the same name as newname, the server must return NFS4ERR_EXIST.

For the target directory, the server returns change_info4 information in cinfo. With the atomic field of the change_info4 struct, the server will indicate if the before and after change attributes were obtained atomically with respect to the link creation.

If the newname has a length of 0 (zero), or if newname does not obey the UTF-8 definition, the error NFS4ERR_INVAL will be returned.

15.11.5. IMPLEMENTATION

Changes to any property of the "hard" linked files are reflected in all of the linked files. When a link is made to a file, the attributes for the file should have a value for numlinks that is one greater than the value before the LINK operation.

The statement "file and the target directory must reside within the same filesystem on the server" means that the fsid fields in the attributes for the objects are the same. If they reside on different filesystems, the error, NFS4ERR_XDEV, is returned. On some servers, the filenames, "." and "..", are illegal as newname.

In the case that newname is already linked to the file represented by the saved filehandle, the server will return NFS4ERR_EXIST.

Note that symbolic links are created with the CREATE operation.

15.12. Operation 12: LOCK - Create Lock

15.12.1. SYNOPSIS

(cfh) locktype, reclaim, offset, length, locker -> stateid

15.12.2. ARGUMENT

```
enum nfs_lock_type4 {
        READ_LT         = 1,
        WRITE_LT        = 2,
        READW_LT        = 3,    /* blocking read */
        WRITEW_LT       = 4     /* blocking write */
};
```

```
   /*
    * For LOCK, transition from open_owner to new lock_owner
    */
   struct open_to_lock_owner4 {
           seqid4          open_seqid;
           stateid4        open_stateid;
           seqid4          lock_seqid;
           lock_owner4     lock_owner;
   };

   /*
    * For LOCK, existing lock_owner continues to request file locks
    */
   struct exist_lock_owner4 {
           stateid4        lock_stateid;
           seqid4          lock_seqid;
   };

   union locker4 switch (bool new_lock_owner) {
    case TRUE:
           open_to_lock_owner4     open_owner;
    case FALSE:
           exist_lock_owner4       lock_owner;
   };

   /*
    * LOCK/LOCKT/LOCKU: Record lock management
    */
   struct LOCK4args {
           /* CURRENT_FH: file */
           nfs_lock_type4  locktype;
           bool            reclaim;
           offset4         offset;
           length4         length;
           locker4         locker;
   };
```

15.12.3. RESULT

```
struct LOCK4denied {
        offset4         offset;
        length4         length;
        nfs_lock_type4  locktype;
        lock_owner4     owner;
};

struct LOCK4resok {
        stateid4        lock_stateid;
};

union LOCK4res switch (nfsstat4 status) {
 case NFS4_OK:
         LOCK4resok     resok4;
 case NFS4ERR_DENIED:
         LOCK4denied    denied;
 default:
         void;
};
```

15.12.4. DESCRIPTION

The LOCK operation requests a byte-range lock for the byte range specified by the offset and length parameters. The lock type is also specified to be one of the nfs_lock_type4s. If this is a reclaim request, the reclaim parameter will be TRUE;

Bytes in a file may be locked even if those bytes are not currently allocated to the file. To lock the file from a specific offset through the end-of-file (no matter how long the file actually is) use a length field with all bits set to 1 (one). If the length is zero, or if a length which is not all bits set to one is specified, and length when added to the offset exceeds the maximum 64-bit unsigned integer value, the error NFS4ERR_INVAL will result.

Some servers may only support locking for byte offsets that fit within 32 bits. If the client specifies a range that includes a byte beyond the last byte offset of the 32-bit range, but does not include the last byte offset of the 32-bit and all of the byte offsets beyond it, up to the end of the valid 64-bit range, such a 32-bit server MUST return the error NFS4ERR_BAD_RANGE.

In the case that the lock is denied, the owner, offset, and length of a conflicting lock are returned.

On success, the current filehandle retains its value.

15.12.5. IMPLEMENTATION

If the server is unable to determine the exact offset and length of the conflicting lock, the same offset and length that were provided in the arguments should be returned in the denied results. Section 9 contains a full description of this and the other file locking operations.

LOCK operations are subject to permission checks and to checks against the access type of the associated file. However, the specific right and modes required for various type of locks, reflect the semantics of the server-exported filesystem, and are not specified by the protocol. For example, Windows 2000 allows a write lock of a file open for READ, while a POSIX-compliant system does not.

When the client makes a lock request that corresponds to a range that the lock-owner has locked already (with the same or different lock type), or to a sub-region of such a range, or to a region which includes multiple locks already granted to that lock-owner, in whole or in part, and the server does not support such locking operations (i.e., does not support POSIX locking semantics), the server will return the error NFS4ERR_LOCK_RANGE. In that case, the client may return an error, or it may emulate the required operations, using only LOCK for ranges that do not include any bytes already locked by that lock-owner and LOCKU of locks held by that lock-owner (specifying an exactly-matching range and type). Similarly, when the client makes a lock request that amounts to upgrading (changing from a read lock to a write lock) or downgrading (changing from write lock to a read lock) an existing record lock, and the server does not support such a lock, the server will return NFS4ERR_LOCK_NOTSUPP. Such operations may not perfectly reflect the required semantics in the face of conflicting lock requests from other clients.

When a client holds an OPEN_DELEGATE_WRITE delegation, the client holding that delegation is assured that there are no opens by other clients. Thus, there can be no conflicting LOCK operations from such clients. Therefore, the client may be handling locking requests locally, without doing LOCK operations on the server. If it does that, it must be prepared to update the lock status on the server, by sending appropriate LOCK and LOCKU operations before returning the delegation.

When one or more clients hold OPEN_DELEGATE_READ delegations, any LOCK operation where the server is implementing mandatory locking semantics MUST result in the recall of all such delegations. The

LOCK operation may not be granted until all such delegations are returned or revoked. Except where this happens very quickly, one or more NFS4ERR_DELAY errors will be returned to requests made while the delegation remains outstanding.

The locker argument specifies the lock-owner that is associated with the LOCK request. The locker4 structure is a switched union that indicates whether the client has already created byte-range locking state associated with the current open file and lock-owner. There are multiple cases to be considered, corresponding to possible combinations of whether locking state has been created for the current open file and lock-owner, and whether the boolean new_lock_owner is set. In all of the cases, there is a lock_seqid specified, whether the lock-owner is specified explicitly or implicitly. This seqid value is used for checking lock-owner sequencing/replay issues. When the given lock-owner is not known to the server, this establishes an initial sequence value for the new lock-owner.

- In the case in which the state has been created and the boolean is false, the only part of the argument other than lock_seqid is just a stateid representing the set of locks associated with that open file and lock-owner.

- In the case in which the state has been created and the boolean is true, the server rejects the request with the error NFS4ERR_BAD_SEQID. The only exception is where there is a retransmission of a previous request in which the boolean was true. In this case, the lock_seqid will match the original request and the response will reflect the final case, below.

- In the case where no byte-range locking state has been established and the boolean is true, the argument contains an open_to_lock_owner structure which specifies the stateid of the open file and the lock-owner to be used for the lock. Note that although the open-owner is not given explicitly, the open_seqid associated with it is used to check for open-owner sequencing issues. This case provides a method to use the established state of the open_stateid to transition to the use of a lock stateid.

15.13. Operation 13: LOCKT - Test For Lock

15.13.1. SYNOPSIS

(cfh) locktype, offset, length, owner -> {void, NFS4ERR_DENIED -> owner}

15.13.2. ARGUMENT

```
struct LOCKT4args {
        /* CURRENT_FH: file */
        nfs_lock_type4  locktype;
        offset4         offset;
        length4         length;
        lock_owner4     owner;
};
```

15.13.3. RESULT

```
union LOCKT4res switch (nfsstat4 status) {
 case NFS4ERR_DENIED:
         LOCK4denied    denied;
 case NFS4_OK:
         void;
 default:
         void;
};
```

15.13.4. DESCRIPTION

The LOCKT operation tests the lock as specified in the arguments. If a conflicting lock exists, the owner, offset, length, and type of the conflicting lock are returned; if no lock is held, nothing other than NFS4_OK is returned. Lock types READ_LT and READW_LT are processed in the same way in that a conflicting lock test is done without regard to blocking or non-blocking. The same is true for WRITE_LT and WRITEW_LT.

The ranges are specified as for LOCK. The NFS4ERR_INVAL and NFS4ERR_BAD_RANGE errors are returned under the same circumstances as for LOCK.

On success, the current filehandle retains its value.

15.13.5. IMPLEMENTATION

If the server is unable to determine the exact offset and length of the conflicting lock, the same offset and length that were provided in the arguments should be returned in the denied results. Section 9 contains further discussion of the file locking mechanisms.

LOCKT uses a lock_owner4 rather a stateid4, as is used in LOCK to identify the owner. This is because the client does not have to open

the file to test for the existence of a lock, so a stateid may not be available.

The test for conflicting locks SHOULD exclude locks for the current lock-owner. Note that since such locks are not examined the possible existence of overlapping ranges may not affect the results of LOCKT. If the server does examine locks that match the lock-owner for the purpose of range checking, NFS4ERR_LOCK_RANGE may be returned. In the event that it returns NFS4_OK, clients may do a LOCK and receive NFS4ERR_LOCK_RANGE on the LOCK request because of the flexibility provided to the server.

When a client holds an OPEN_DELEGATE_WRITE delegation, it may choose (see Section 15.12.5)) to handle LOCK requests locally. In such a case, LOCKT requests will similarly be handled locally.

15.14. Operation 14: LOCKU - Unlock File

15.14.1. SYNOPSIS

(cfh) type, seqid, stateid, offset, length -> stateid

15.14.2. ARGUMENT

```
struct LOCKU4args {
        /* CURRENT_FH: file */
        nfs_lock_type4  locktype;
        seqid4          seqid;
        stateid4        lock_stateid;
        offset4         offset;
        length4         length;
};
```

15.14.3. RESULT

```
union LOCKU4res switch (nfsstat4 status) {
 case   NFS4_OK:
         stateid4       lock_stateid;
 default:
         void;
};
```

15.14.4. DESCRIPTION

The LOCKU operation unlocks the byte-range lock specified by the parameters. The client may set the locktype field to any value that is legal for the nfs_lock_type4 enumerated type, and the server MUST accept any legal value for locktype. Any legal value for locktype has no effect on the success or failure of the LOCKU operation.

The ranges are specified as for LOCK. The NFS4ERR_INVAL and NFS4ERR_BAD_RANGE errors are returned under the same circumstances as for LOCK.

On success, the current filehandle retains its value.

15.14.5. IMPLEMENTATION

If the area to be unlocked does not correspond exactly to a lock actually held by the lock-owner the server may return the error NFS4ERR_LOCK_RANGE. This includes the case in which the area is not locked, where the area is a sub-range of the area locked, where it overlaps the area locked without matching exactly or the area specified includes multiple locks held by the lock-owner. In all of these cases, allowed by POSIX locking [35] semantics, a client receiving this error, should if it desires support for such operations, simulate the operation using LOCKU on ranges corresponding to locks it actually holds, possibly followed by LOCK requests for the sub-ranges not being unlocked.

When a client holds an OPEN_DELEGATE_WRITE delegation, it may choose (see Section 15.12.5)) to handle LOCK requests locally. In such a case, LOCKU requests will similarly be handled locally.

15.15. Operation 15: LOOKUP - Lookup Filename

15.15.1. SYNOPSIS

(cfh), component -> (cfh)

15.15.2. ARGUMENT

```
struct LOOKUP4args {
        /* CURRENT_FH: directory */
        component4      objname;
};
```

15.15.3. RESULT

```
struct LOOKUP4res {
        /* CURRENT_FH: object */
        nfsstat4        status;
};
```

15.15.4. DESCRIPTION

This operation LOOKUPs or finds a filesystem object using the directory specified by the current filehandle. LOOKUP evaluates the component and if the object exists the current filehandle is replaced with the component's filehandle.

If the component cannot be evaluated either because it does not exist or because the client does not have permission to evaluate the component, then an error will be returned and the current filehandle will be unchanged.

If the component is of zero length, NFS4ERR_INVAL will be returned. The component is also subject to the normal UTF-8, character support, and name checks. See Section 12.3 for further discussion.

15.15.5. IMPLEMENTATION

If the client wants to achieve the effect of a multi-component lookup, it may construct a COMPOUND request such as (and obtain each filehandle):

```
PUTFH  (directory filehandle)
LOOKUP "pub"
GETFH
LOOKUP "foo"
GETFH
LOOKUP "bar"
GETFH
```

NFSv4 servers depart from the semantics of previous NFS versions in allowing LOOKUP requests to cross mount points on the server. The client can detect a mount point crossing by comparing the fsid attribute of the directory with the fsid attribute of the directory looked up. If the fsids are different then the new directory is a server mount point. UNIX clients that detect a mount point crossing will need to mount the server's filesystem. This needs to be done to maintain the file object identity checking mechanisms common to UNIX clients.

Servers that limit NFS access to "shares" or "exported" filesystems should provide a pseudo-filesystem into which the exported filesystems can be integrated, so that clients can browse the server's name space. The clients' view of a pseudo filesystem will be limited to paths that lead to exported filesystems.

Note: previous versions of the protocol assigned special semantics to the names "." and "..". NFSv4 assigns no special semantics to these names. The LOOKUPP operator must be used to lookup a parent directory.

Note that this operation does not follow symbolic links. The client is responsible for all parsing of filenames including filenames that are modified by symbolic links encountered during the lookup process.

If the current filehandle supplied is not a directory but a symbolic link, the error NFS4ERR_SYMLINK is returned as the error. For all other non-directory file types, the error NFS4ERR_NOTDIR is returned.

15.16. Operation 16: LOOKUPP - Lookup Parent Directory

15.16.1. SYNOPSIS

```
(cfh) -> (cfh)
```

15.16.2. ARGUMENT

```
/* CURRENT_FH: object */
void;
```

15.16.3. RESULT

```
struct LOOKUPP4res {
        /* CURRENT_FH: directory */
        nfsstat4        status;
};
```

15.16.4. DESCRIPTION

The current filehandle is assumed to refer to a regular directory or a named attribute directory. LOOKUPP assigns the filehandle for its parent directory to be the current filehandle. If there is no parent directory an NFS4ERR_NOENT error must be returned. Therefore, NFS4ERR_NOENT will be returned by the server when the current filehandle is at the root or top of the server's file tree.

15.16.5. IMPLEMENTATION

As for LOOKUP, LOOKUPP will also cross mount points.

If the current filehandle is not a directory or named attribute directory, the error NFS4ERR_NOTDIR is returned.

15.17. Operation 17: NVERIFY - Verify Difference in Attributes

15.17.1. SYNOPSIS

```
  (cfh), fattr -> -
```

15.17.2. ARGUMENT

```
struct NVERIFY4args {
        /* CURRENT_FH: object */
        fattr4          obj_attributes;
};
```

15.17.3. RESULT

```
struct NVERIFY4res {
        nfsstat4        status;
};
```

15.17.4. DESCRIPTION

This operation is used to prefix a sequence of operations to be performed if one or more attributes have changed on some filesystem object. If all the attributes match then the error NFS4ERR_SAME must be returned.

On success, the current filehandle retains its value.

15.17.5. IMPLEMENTATION

This operation is useful as a cache validation operator. If the object to which the attributes belong has changed then the following operations may obtain new data associated with that object. For instance, to check if a file has been changed and obtain new data if it has:

```
  PUTFH  (public)
  LOOKUP "foobar"
  NVERIFY attrbits attrs
```

READ 0 32767

In the case that a recommended attribute is specified in the NVERIFY operation and the server does not support that attribute for the filesystem object, the error NFS4ERR_ATTRNOTSUPP is returned to the client.

When the attribute rdattr_error or any write-only attribute (e.g., time_modify_set) is specified, the error NFS4ERR_INVAL is returned to the client.

15.18. Operation 18: OPEN - Open a Regular File

15.18.1. SYNOPSIS

(cfh), seqid, share_access, share_deny, owner, openhow, claim -> (cfh), stateid, cinfo, rflags, attrset, delegation

15.18.2. ARGUMENT

```
/*
 * Various definitions for OPEN
 */
enum createmode4 {
        UNCHECKED4      = 0,
        GUARDED4        = 1,
        EXCLUSIVE4      = 2
};

union createhow4 switch (createmode4 mode) {
 case UNCHECKED4:
 case GUARDED4:
         fattr4         createattrs;
 case EXCLUSIVE4:
         verifier4      createverf;
};

enum opentype4 {
        OPEN4_NOCREATE  = 0,
        OPEN4_CREATE    = 1
};

union openflag4 switch (opentype4 opentype) {
 case OPEN4_CREATE:
         createhow4     how;
 default:
         void;
};
```

```
   /* Next definitions used for OPEN delegation */
   enum limit_by4 {
           NFS_LIMIT_SIZE          = 1,
           NFS_LIMIT_BLOCKS        = 2
           /* others as needed */
   };

   struct nfs_modified_limit4 {
           uint32_t        num_blocks;
           uint32_t        bytes_per_block;
   };

   union nfs_space_limit4 switch (limit_by4 limitby) {
    /* limit specified as file size */
    case NFS_LIMIT_SIZE:
            uint64_t              filesize;
    /* limit specified by number of blocks */
    case NFS_LIMIT_BLOCKS:
            nfs_modified_limit4    mod_blocks;
   } ;

   enum open_delegation_type4 {
           OPEN_DELEGATE_NONE      = 0,
           OPEN_DELEGATE_READ      = 1,
           OPEN_DELEGATE_WRITE     = 2
   };

   enum open_claim_type4 {
           CLAIM_NULL              = 0,
           CLAIM_PREVIOUS          = 1,
           CLAIM_DELEGATE_CUR      = 2,
           CLAIM_DELEGATE_PREV     = 3
   };

   struct open_claim_delegate_cur4 {
           stateid4        delegate_stateid;
           component4      file;
   };

   union open_claim4 switch (open_claim_type4 claim) {
    /*
     * No special rights to file.
     * Ordinary OPEN of the specified file.
     */
    case CLAIM_NULL:
           /* CURRENT_FH: directory */
           component4      file;
    /*
```

```
     * Right to the file established by an
     * open previous to server reboot. File
     * identified by filehandle obtained at
     * that time rather than by name.
     */
    case CLAIM_PREVIOUS:
           /* CURRENT_FH: file being reclaimed */
           open_delegation_type4   delegate_type;

    /*
     * Right to file based on a delegation
     * granted by the server. File is
     * specified by name.
     */
    case CLAIM_DELEGATE_CUR:
           /* CURRENT_FH: directory */
           open_claim_delegate_cur4        delegate_cur_info;

    /*
     * Right to file based on a delegation
     * granted to a previous boot instance
     * of the client.  File is specified by name.
     */
    case CLAIM_DELEGATE_PREV:
            /* CURRENT_FH: directory */
           component4      file_delegate_prev;
   };

   /*
    * OPEN: Open a file, potentially receiving an open delegation
    */
   struct OPEN4args {
           seqid4          seqid;
           uint32_t        share_access;
           uint32_t        share_deny;
           open_owner4     owner;
           openflag4       openhow;
           open_claim4     claim;
   };
```

15.18.3. RESULT

```
   struct open_read_delegation4 {
    stateid4 stateid;    /* Stateid for delegation*/
    bool     recall;     /* Pre-recalled flag for
                            delegations obtained
                            by reclaim (CLAIM_PREVIOUS) */
```

```
    nfsace4 permissions; /* Defines users who don't
                            need an ACCESS call to
                            open for read */
   };

   struct open_write_delegation4 {
    stateid4 stateid;      /* Stateid for delegation */
    bool     recall;       /* Pre-recalled flag for
                              delegations obtained
                              by reclaim
                              (CLAIM_PREVIOUS) */

    nfs_space_limit4
              space_limit; /* Defines condition that
                              the client must check to
                              determine whether the
                              file needs to be flushed
                              to the server on close.  */

    nfsace4   permissions; /* Defines users who don't
                              need an ACCESS call as
                              part of a delegated
                              open. */
   };

   union open_delegation4
   switch (open_delegation_type4 delegation_type) {
           case OPEN_DELEGATE_NONE:
                   void;
           case OPEN_DELEGATE_READ:
                   open_read_delegation4 read;
           case OPEN_DELEGATE_WRITE:
                   open_write_delegation4 write;
   };

   /*
    * Result flags
    */

   /* Client must confirm open */
   const OPEN4_RESULT_CONFIRM      = 0x00000002;
   /* Type of file locking behavior at the server */
   const OPEN4_RESULT_LOCKTYPE_POSIX = 0x00000004;

   struct OPEN4resok {
    stateid4       stateid;      /* Stateid for open */
    change_info4   cinfo;        /* Directory Change Info */
    uint32_t       rflags;       /* Result flags */
```

```
    bitmap4        attrset;      /* attribute set for create*/
    open_delegation4 delegation; /* Info on any open
                                    delegation */
   };

   union OPEN4res switch (nfsstat4 status) {
    case NFS4_OK:
           /* CURRENT_FH: opened file */
           OPEN4resok      resok4;
    default:
           void;
   };
```

15.18.4. Warning to Client Implementors

OPEN resembles LOOKUP in that it generates a filehandle for the client to use. Unlike LOOKUP though, OPEN creates server state on the filehandle. In normal circumstances, the client can only release this state with a CLOSE operation. CLOSE uses the current filehandle to determine which file to close. Therefore, the client MUST follow every OPEN operation with a GETFH operation in the same COMPOUND procedure. This will supply the client with the filehandle such that CLOSE can be used appropriately.

Simply waiting for the lease on the file to expire is insufficient because the server may maintain the state indefinitely as long as another client does not attempt to make a conflicting access to the same file.

15.18.5. DESCRIPTION

The OPEN operation creates and/or opens a regular file in a directory with the provided name. If the file does not exist at the server and creation is desired, specification of the method of creation is provided by the openhow parameter. The client has the choice of three creation methods: UNCHECKED4, GUARDED4, or EXCLUSIVE4.

If the current filehandle is a named attribute directory, OPEN will then create or open a named attribute file. Note that exclusive create of a named attribute is not supported. If the createmode is EXCLUSIVE4 and the current filehandle is a named attribute directory, the server will return EINVAL.

UNCHECKED4 means that the file should be created if a file of that name does not exist and encountering an existing regular file of that name is not an error. For this type of create, createattrs specifies the initial set of attributes for the file. The set of attributes

may include any writable attribute valid for regular files. When an UNCHECKED4 create encounters an existing file, the attributes specified by createattrs are not used, except that when an size of zero is specified, the existing file is truncated. If GUARDED4 is specified, the server checks for the presence of a duplicate object by name before performing the create. If a duplicate exists, an error of NFS4ERR_EXIST is returned as the status. If the object does not exist, the request is performed as described for UNCHECKED4. For each of these cases (UNCHECKED4 and GUARDED4) where the operation is successful, the server will return to the client an attribute mask signifying which attributes were successfully set for the object.

EXCLUSIVE4 specifies that the server is to follow exclusive creation semantics, using the verifier to ensure exclusive creation of the target. The server should check for the presence of a duplicate object by name. If the object does not exist, the server creates the object and stores the verifier with the object. If the object does exist and the stored verifier matches the client provided verifier, the server uses the existing object as the newly created object. If the stored verifier does not match, then an error of NFS4ERR_EXIST is returned. No attributes may be provided in this case, since the server may use an attribute of the target object to store the verifier. If the server uses an attribute to store the exclusive create verifier, it will signify which attribute by setting the appropriate bit in the attribute mask that is returned in the results.

For the target directory, the server returns change_info4 information in cinfo. With the atomic field of the change_info4 struct, the server will indicate if the before and after change attributes were obtained atomically with respect to the link creation.

Upon successful creation, the current filehandle is replaced by that of the new object.

The OPEN operation provides for Windows share reservation capability with the use of the share_access and share_deny fields of the OPEN arguments. The client specifies at OPEN the required share_access and share_deny modes. For clients that do not directly support SHAREs (i.e., UNIX), the expected deny value is DENY_NONE. In the case that there is a existing SHARE reservation that conflicts with the OPEN request, the server returns the error NFS4ERR_SHARE_DENIED. For a complete SHARE request, the client must provide values for the owner and seqid fields for the OPEN argument. For additional discussion of SHARE semantics see Section 9.9.

In the case that the client is recovering state from a server failure, the claim field of the OPEN argument is used to signify that

the request is meant to reclaim state previously held.

The "claim" field of the OPEN argument is used to specify the file to be opened and the state information which the client claims to possess. There are four basic claim types which cover the various situations for an OPEN. They are as follows:

CLAIM_NULL: For the client, this is a new OPEN request and there is no previous state associate with the file for the client.

CLAIM_PREVIOUS: The client is claiming basic OPEN state for a file that was held previous to a server reboot. Generally used when a server is returning persistent filehandles; the client may not have the file name to reclaim the OPEN.

CLAIM_DELEGATE_CUR: The client is claiming a delegation for OPEN as granted by the server. Generally this is done as part of recalling a delegation.

CLAIM_DELEGATE_PREV: The client is claiming a delegation granted to a previous client instance. This claim type is for use after a SETCLIENTID_CONFIRM and before the corresponding DELEGPURGE in two situations: after a client reboot and after a lease expiration that resulted in loss of all lock state. The server MAY support CLAIM_DELEGATE_PREV. If it does support CLAIM_DELEGATE_PREV, SETCLIENTID_CONFIRM MUST NOT remove the client's delegation state, and the server MUST support the DELEGPURGE operation.

The following errors apply to use of the CLAIM_DELEGATE_PREV claim type:

- NFS4ERR_NOTSUPP is returned if the server does not support this claim type.

- NFS4ERR_INVAL is returned if the reclaim is done at an inappropriate time, e.g., after DELEGPURGE has been done.

- NFS4ERR_BAD_RECLAIM is returned if the other error conditions do not apply and the server has no record of the delegation whose reclaim is being attempted.

For OPEN requests whose claim type is other than CLAIM_PREVIOUS (i.e., requests other than those devoted to reclaiming opens after a server reboot) that reach the server during its grace or lease expiration period, the server returns an error of NFS4ERR_GRACE.

For any OPEN request, the server may return an open delegation, which allows further opens and closes to be handled locally on the client

as described in Section 10.4. Note that delegation is up to the server to decide. The client should never assume that delegation will or will not be granted in a particular instance. It should always be prepared for either case. A partial exception is the reclaim (CLAIM_PREVIOUS) case, in which a delegation type is claimed. In this case, delegation will always be granted, although the server may specify an immediate recall in the delegation structure.

The rflags returned by a successful OPEN allow the server to return information governing how the open file is to be handled.

OPEN4_RESULT_CONFIRM indicates that the client MUST execute an OPEN_CONFIRM operation before using the open file. OPEN4_RESULT_LOCKTYPE_POSIX indicates the server's file locking behavior supports the complete set of Posix locking techniques [35]. From this the client can choose to manage file locking state in a way to handle a mis-match of file locking management.

If the component is of zero length, NFS4ERR_INVAL will be returned. The component is also subject to the normal UTF-8, character support, and name checks. See Section 12.3 for further discussion.

When an OPEN is done and the specified open-owner already has the resulting filehandle open, the result is to "OR" together the new share and deny status together with the existing status. In this case, only a single CLOSE need be done, even though multiple OPENs were completed. When such an OPEN is done, checking of share reservations for the new OPEN proceeds normally, with no exception for the existing OPEN held by the same owner. In this case, the stateid returned as an "other" field that matches that of the previous open while the "seqid" field is incremented to reflect the change status due to the new open.

If the underlying filesystem at the server is only accessible in a read-only mode and the OPEN request has specified ACCESS_WRITE or ACCESS_BOTH, the server will return NFS4ERR_ROFS to indicate a read-only filesystem.

As with the CREATE operation, the server MUST derive the owner, owner ACE, group, or group ACE if any of the four attributes are required and supported by the server's filesystem. For an OPEN with the EXCLUSIVE4 createmode, the server has no choice, since such OPEN calls do not include the createattrs field. Conversely, if createattrs is specified, and includes owner or group (or corresponding ACEs) that the principal in the RPC call's credentials does not have authorization to create files for, then the server may return NFS4ERR_PERM.

In the case of a OPEN which specifies a size of zero (e.g., truncation) and the file has named attributes, the named attributes are left as is. They are not removed.

15.18.6. IMPLEMENTATION

The OPEN operation contains support for EXCLUSIVE4 create. The mechanism is similar to the support in NFSv3 [14]. As in NFSv3, this mechanism provides reliable exclusive creation. Exclusive create is invoked when the how parameter is EXCLUSIVE4. In this case, the client provides a verifier that can reasonably be expected to be unique. A combination of a client identifier, perhaps the client network address, and a unique number generated by the client, perhaps the RPC transaction identifier, may be appropriate.

If the object does not exist, the server creates the object and stores the verifier in stable storage. For filesystems that do not provide a mechanism for the storage of arbitrary file attributes, the server may use one or more elements of the object meta-data to store the verifier. The verifier must be stored in stable storage to prevent erroneous failure on retransmission of the request. It is assumed that an exclusive create is being performed because exclusive semantics are critical to the application. Because of the expected usage, exclusive CREATE does not rely solely on the normally volatile duplicate request cache for storage of the verifier. The duplicate request cache in volatile storage does not survive a crash and may actually flush on a long network partition, opening failure windows. In the UNIX local filesystem environment, the expected storage location for the verifier on creation is the meta-data (time stamps) of the object. For this reason, an exclusive object create may not include initial attributes because the server would have nowhere to store the verifier.

If the server cannot support these exclusive create semantics, possibly because of the requirement to commit the verifier to stable storage, it should fail the OPEN request with the error, NFS4ERR_NOTSUPP.

During an exclusive CREATE request, if the object already exists, the server reconstructs the object's verifier and compares it with the verifier in the request. If they match, the server treats the request as a success. The request is presumed to be a duplicate of an earlier, successful request for which the reply was lost and that the server duplicate request cache mechanism did not detect. If the verifiers do not match, the request is rejected with the status, NFS4ERR_EXIST.

Once the client has performed a successful exclusive create, it must

issue a SETATTR to set the correct object attributes. Until it does so, it should not rely upon any of the object attributes, since the server implementation may need to overload object meta-data to store the verifier. The subsequent SETATTR must not occur in the same COMPOUND request as the OPEN. This separation will guarantee that the exclusive create mechanism will continue to function properly in the face of retransmission of the request.

Use of the GUARDED4 attribute does not provide exactly-once semantics. In particular, if a reply is lost and the server does not detect the retransmission of the request, the operation can fail with NFS4ERR_EXIST, even though the create was performed successfully. The client would use this behavior in the case that the application has not requested an exclusive create but has asked to have the file truncated when the file is opened. In the case of the client timing out and retransmitting the create request, the client can use GUARDED4 to prevent against a sequence like: create, write, create (retransmitted) from occurring.

For SHARE reservations, the client must specify a value for share_access that is one of READ, WRITE, or BOTH. For share_deny, the client must specify one of NONE, READ, WRITE, or BOTH. If the client fails to do this, the server must return NFS4ERR_INVAL.

Based on the share_access value (READ, WRITE, or BOTH) the client should check that the requester has the proper access rights to perform the specified operation. This would generally be the results of applying the ACL access rules to the file for the current requester. However, just as with the ACCESS operation, the client should not attempt to second-guess the server's decisions, as access rights may change and may be subject to server administrative controls outside the ACL framework. If the requester is not authorized to READ or WRITE (depending on the share_access value), the server must return NFS4ERR_ACCESS. Note that since the NFS version 4 protocol does not impose any requirement that READs and WRITEs issued for an open file have the same credentials as the OPEN itself, the server still must do appropriate access checking on the READs and WRITEs themselves.

If the component provided to OPEN resolves to something other than a regular file, an error will be returned to the client. If it is a directory, NFS4ERR_ISDIR is returned; otherwise, NFS4ERR_SYMLINK is returned. Note that NFS4ERR_SYMLINK is returned for both symlinks and for special files of other types; NFS4ERR_INVAL would be inappropriate, since the arguments provided by the client were correct, and the client cannot necessarily know at the time it sent the OPEN that the component would resolve to a non-regular file.

If the current filehandle is not a directory, the error NFS4ERR_NOTDIR will be returned.

If a COMPOUND contains an OPEN which establishes a OPEN_DELEGATE_WRITE delegation, then a subsequent GETATTR inside that COMPOUND SHOULD not result in a CB_GETATTR to the client. The server SHOULD understand the GETATTR to be for the same client ID and avoid querying the client, which will not be able to respond. This sequence of OPEN, GETATTR SHOULD be understood as an atomic retrieval of the initial size and change attribute. Further, the client SHOULD NOT construct a COMPOUND which mixes operations for different client IDs.

15.19. Operation 19: OPENATTR - Open Named Attribute Directory

15.19.1. SYNOPSIS

```
(cfh) createdir -> (cfh)
```

15.19.2. ARGUMENT

```
struct OPENATTR4args {
        /* CURRENT_FH: object */
        bool    createdir;
};
```

15.19.3. RESULT

```
struct OPENATTR4res {
        /* CURRENT_FH: named attr directory */
        nfsstat4        status;
};
```

15.19.4. DESCRIPTION

The OPENATTR operation is used to obtain the filehandle of the named attribute directory associated with the current filehandle. The result of the OPENATTR will be a filehandle to an object of type NF4ATTRDIR. From this filehandle, READDIR and LOOKUP operations can be used to obtain filehandles for the various named attributes associated with the original filesystem object. Filehandles returned within the named attribute directory will have a type of NF4NAMEDATTR.

The createdir argument allows the client to signify if a named attribute directory should be created as a result of the OPENATTR

operation. Some clients may use the OPENATTR operation with a value of FALSE for createdir to determine if any named attributes exist for the object. If none exist, then NFS4ERR_NOENT will be returned. If createdir has a value of TRUE and no named attribute directory exists, one is created. The creation of a named attribute directory assumes that the server has implemented named attribute support in this fashion and is not required to do so by this definition.

15.19.5. IMPLEMENTATION

If the server does not support named attributes for the current filehandle, an error of NFS4ERR_NOTSUPP will be returned to the client.

15.20. Operation 20: OPEN_CONFIRM - Confirm Open

15.20.1. SYNOPSIS

(cfh), seqid, stateid -> stateid

15.20.2. ARGUMENT

```
struct OPEN_CONFIRM4args {
        /* CURRENT_FH: opened file */
        stateid4        open_stateid;
        seqid4          seqid;
};
```

15.20.3. RESULT

```
struct OPEN_CONFIRM4resok {
        stateid4        open_stateid;
};

union OPEN_CONFIRM4res switch (nfsstat4 status) {
 case NFS4_OK:
         OPEN_CONFIRM4resok     resok4;
 default:
         void;
};
```

15.20.4. DESCRIPTION

This operation is used to confirm the sequence id usage for the first time that a open-owner is used by a client. The stateid returned from the OPEN operation is used as the argument for this operation

along with the next sequence id for the open-owner. The sequence id passed to the OPEN_CONFIRM must be 1 (one) greater than the seqid passed to the OPEN operation. If the server receives an unexpected sequence id with respect to the original open, then the server assumes that the client will not confirm the original OPEN and all state associated with the original OPEN is released by the server.

On success, the current filehandle retains its value.

15.20.5. IMPLEMENTATION

A given client might generate many open_owner4 data structures for a given client ID. The client will periodically either dispose of its open_owner4s or stop using them for indefinite periods of time. The latter situation is why the NFSv4 protocol does not have an explicit operation to exit an open_owner4: such an operation is of no use in that situation. Instead, to avoid unbounded memory use, the server needs to implement a strategy for disposing of open_owner4s that have no current open state for any files and have not been used recently. The time period used to determine when to dispose of open_owner4s is an implementation choice. The time period should certainly be no less than the lease time plus any grace period the server wishes to implement beyond a lease time. The OPEN_CONFIRM operation allows the server to safely dispose of unused open_owner4 data structures.

In the case that a client issues an OPEN operation and the server no longer has a record of the open_owner4, the server needs to ensure that this is a new OPEN and not a replay or retransmission.

Servers must not require confirmation on OPENs that grant delegations or are doing reclaim operations. See Section 9.1.10 for details. The server can easily avoid this by noting whether it has disposed of one open_owner4 for the given client ID. If the server does not support delegation, it might simply maintain a single bit that notes whether any open_owner4 (for any client) has been disposed of.

The server must hold unconfirmed OPEN state until one of three events occur. First, the client sends an OPEN_CONFIRM request with the appropriate sequence id and stateid within the lease period. In this case, the OPEN state on the server goes to confirmed, and the open_owner4 on the server is fully established.

Second, the client sends another OPEN request with a sequence id that is incorrect for the open_owner4 (out of sequence). In this case, the server assumes the second OPEN request is valid and the first one is a replay. The server cancels the OPEN state of the first OPEN request, establishes an unconfirmed OPEN state for the second OPEN request, and responds to the second OPEN request with an indication

that an OPEN_CONFIRM is needed. The process then repeats itself. While there is a potential for a denial of service attack on the client, it is mitigated if the client and server require the use of a security flavor based on Kerberos V5 or some other flavor that uses cryptography.

What if the server is in the unconfirmed OPEN state for a given open_owner4, and it receives an operation on the open_owner4 that has a stateid but the operation is not OPEN, or it is OPEN_CONFIRM but with the wrong stateid? Then, even if the seqid is correct, the server returns NFS4ERR_BAD_STATEID, because the server assumes the operation is a replay: if the server has no established OPEN state, then there is no way, for example, a LOCK operation could be valid.

Third, neither of the two aforementioned events occur for the open_owner4 within the lease period. In this case, the OPEN state is canceled and disposal of the open_owner4 can occur.

15.21. Operation 21: OPEN_DOWNGRADE - Reduce Open File Access

15.21.1. SYNOPSIS

(cfh), stateid, seqid, access, deny -> stateid

15.21.2. ARGUMENT

```
struct OPEN_DOWNGRADE4args {
        /* CURRENT_FH: opened file */
        stateid4        open_stateid;
        seqid4          seqid;
        uint32_t        share_access;
        uint32_t        share_deny;
};
```

15.21.3. RESULT

```
struct OPEN_DOWNGRADE4resok {
        stateid4        open_stateid;
};

union OPEN_DOWNGRADE4res switch(nfsstat4 status) {
 case NFS4_OK:
        OPEN_DOWNGRADE4resok    resok4;
 default:
         void;
};
```

15.21.4. DESCRIPTION

This operation is used to adjust the share_access and share_deny bits for a given open. This is necessary when a given open-owner opens the same file multiple times with different share_access and share_deny flags. In this situation, a close of one of the opens may change the appropriate share_access and share_deny flags to remove bits associated with opens no longer in effect.

The share_access and share_deny bits specified in this operation replace the current ones for the specified open file. The share_access and share_deny bits specified must be exactly equal to the union of the share_access and share_deny bits specified for some subset of the OPENs in effect for current open-owner on the current file. If that constraint is not respected, the error NFS4ERR_INVAL should be returned. Since share_access and share_deny bits are subsets of those already granted, it is not possible for this request to be denied because of conflicting share reservations.

As the OPEN_DOWNGRADE may change a file to be not-open-for-write and a write byte-range lock might be held, the server may have to reject the OPEN_DOWNGRADE with a NFS4ERR_LOCKS_HELD.

On success, the current filehandle retains its value.

15.22. Operation 22: PUTFH - Set Current Filehandle

15.22.1. SYNOPSIS

```
filehandle -> (cfh)
```

15.22.2. ARGUMENT

```
struct PUTFH4args {
        nfs_fh4         object;
};
```

15.22.3. RESULT

```
struct PUTFH4res {
        /* CURRENT_FH: */
        nfsstat4        status;
};
```

15.22.4. DESCRIPTION

Replaces the current filehandle with the filehandle provided as an argument.

If the security mechanism used by the requester does not meet the requirements of the filehandle provided to this operation, the server MUST return NFS4ERR_WRONGSEC.

See Section 15.2.4.1 for more details on the current filehandle.

15.22.5. IMPLEMENTATION

Commonly used as the first operator in an NFS request to set the context for following operations.

15.23. Operation 23: PUTPUBFH - Set Public Filehandle

15.23.1. SYNOPSIS

```
- -> (cfh)
```

15.23.2. ARGUMENT

```
void;
```

15.23.3. RESULT

```
struct PUTPUBFH4res {
        /* CURRENT_FH: public fh */
        nfsstat4        status;
};
```

15.23.4. DESCRIPTION

Replaces the current filehandle with the filehandle that represents the public filehandle of the server's name space. This filehandle may be different from the "root" filehandle which may be associated with some other directory on the server.

The public filehandle represents the concepts embodied in [23], [24], [38]. The intent for NFSv4 is that the public filehandle (represented by the PUTPUBFH operation) be used as a method of providing WebNFS server compatibility with NFSv2 and NFSv3.

The public filehandle and the root filehandle (represented by the PUTROOTFH operation) should be equivalent. If the public and root

filehandles are not equivalent, then the public filehandle MUST be a descendant of the root filehandle.

15.23.5. IMPLEMENTATION

Used as the first operator in an NFS request to set the context for following operations.

With the NFSv2 and 3 public filehandle, the client is able to specify whether the path name provided in the LOOKUP should be evaluated as either an absolute path relative to the server's root or relative to the public filehandle. [38] contains further discussion of the functionality. With NFSv4, that type of specification is not directly available in the LOOKUP operation. The reason for this is because the component separators needed to specify absolute vs. relative are not allowed in NFSv4. Therefore, the client is responsible for constructing its request such that the use of either PUTROOTFH or PUTPUBFH are used to signify absolute or relative evaluation of an NFS URL respectively.

Note that there are warnings mentioned in [38] with respect to the use of absolute evaluation and the restrictions the server may place on that evaluation with respect to how much of its namespace has been made available. These same warnings apply to NFSv4. It is likely, therefore that because of server implementation details, an NFSv3 absolute public filehandle lookup may behave differently than an NFSv4 absolute resolution.

There is a form of security negotiation as described in [39] that uses the public filehandle a method of employing SNEGO. This method is not available with NFSv4 as filehandles are not overloaded with special meaning and therefore do not provide the same framework as NFSv2 and NFSv3. Clients should therefore use the security negotiation mechanisms described in this RFC.

15.24. Operation 24: PUTROOTFH - Set Root Filehandle

15.24.1. SYNOPSIS

```
- -> (cfh)
```

15.24.2. ARGUMENT

```
void;
```

15.24.3. RESULT

```
struct PUTROOTFH4res {
        /* CURRENT_FH: root fh */
        nfsstat4        status;
};
```

15.24.4. DESCRIPTION

Replaces the current filehandle with the filehandle that represents the root of the server's name space. From this filehandle a LOOKUP operation can locate any other filehandle on the server. This filehandle may be different from the "public" filehandle which may be associated with some other directory on the server.

See Section 15.2.4.1 for more details on the current filehandle.

15.24.5. IMPLEMENTATION

Commonly used as the first operator in an NFS request to set the context for following operations.

15.25. Operation 25: READ - Read from File

15.25.1. SYNOPSIS

(cfh), stateid, offset, count -> eof, data

15.25.2. ARGUMENT

```
struct READ4args {
        /* CURRENT_FH: file */
        stateid4        stateid;
        offset4         offset;
        count4          count;
};
```

15.25.3. RESULT

```
struct READ4resok {
        bool            eof;
        opaque          data<>;
};

union READ4res switch (nfsstat4 status) {
 case NFS4_OK:
         READ4resok     resok4;
 default:
         void;
};
```

15.25.4. DESCRIPTION

The READ operation reads data from the regular file identified by the current filehandle.

The client provides an offset of where the READ is to start and a count of how many bytes are to be read. An offset of 0 (zero) means to read data starting at the beginning of the file. If offset is greater than or equal to the size of the file, the status, NFS4_OK, is returned with a data length set to 0 (zero) and eof is set to TRUE. The READ is subject to access permissions checking.

If the client specifies a count value of 0 (zero), the READ succeeds and returns 0 (zero) bytes of data again subject to access permissions checking. The server may choose to return fewer bytes than specified by the client. The client needs to check for this condition and handle the condition appropriately.

The stateid value for a READ request represents a value returned from a previous byte-range lock or share reservation request or the stateid associated with a delegation. The stateid is used by the server to verify that the associated share reservation and any byte-range locks are still valid and to update lease timeouts for the client.

If the read ended at the end-of-file (formally, in a correctly formed READ request, if offset + count is equal to the size of the file), or the read request extends beyond the size of the file (if offset + count is greater than the size of the file), eof is returned as TRUE; otherwise it is FALSE. A successful READ of an empty file will always return eof as TRUE.

If the current filehandle is not a regular file, an error will be

returned to the client. In the case the current filehandle represents a directory, NFS4ERR_ISDIR is returned; otherwise, NFS4ERR_INVAL is returned.

For a READ with a stateid value of all bits 0, the server MAY allow the READ to be serviced subject to mandatory file locks or the current share deny modes for the file. For a READ with a stateid value of all bits 1, the server MAY allow READ operations to bypass locking checks at the server.

On success, the current filehandle retains its value.

15.25.5. IMPLEMENTATION

If the server returns a "short read" (i.e., fewer data than requested and eof is set to FALSE), the client should send another READ to get the remaining data. A server may return less data than requested under several circumstances. The file may have been truncated by another client or perhaps on the server itself, changing the file size from what the requesting client believes to be the case. This would reduce the actual amount of data available to the client. It is possible that the server reduce the transfer size and so return a short read result. Server resource exhaustion may also occur in a short read.

If mandatory byte-range locking is in effect for the file, and if the byte-range corresponding to the data to be read from the file is WRITE_LT locked by an owner not associated with the stateid, the server will return the NFS4ERR_LOCKED error. The client should try to get the appropriate READ_LT via the LOCK operation before reattempting the READ. When the READ completes, the client should release the byte-range lock via LOCKU.

If another client has an OPEN_DELEGATE_WRITE delegation for the file being read, the delegation must be recalled, and the operation cannot proceed until that delegation is returned or revoked. Except where this happens very quickly, one or more NFS4ERR_DELAY errors will be returned to requests made while the delegation remains outstanding. Normally, delegations will not be recalled as a result of a READ operation since the recall will occur as a result of an earlier OPEN. However, since it is possible for a READ to be done with a special stateid, the server needs to check for this case even though the client should have done an OPEN previously.

15.26. Operation 26: READDIR - Read Directory

15.26.1. SYNOPSIS

```
(cfh), cookie, cookieverf, dircount, maxcount, attr_request ->
cookieverf { cookie, name, attrs }
```

15.26.2. ARGUMENT

```
struct READDIR4args {
        /* CURRENT_FH: directory */
        nfs_cookie4     cookie;
        verifier4       cookieverf;
        count4          dircount;
        count4          maxcount;
        bitmap4         attr_request;
};
```

15.26.3. RESULT

```
struct entry4 {
        nfs_cookie4     cookie;
        component4      name;
        fattr4          attrs;
        entry4          *nextentry;
};

struct dirlist4 {
        entry4          *entries;
        bool            eof;
};

struct READDIR4resok {
        verifier4       cookieverf;
        dirlist4        reply;
};


union READDIR4res switch (nfsstat4 status) {
 case NFS4_OK:
         READDIR4resok  resok4;
 default:
         void;
};
```

15.26.4. DESCRIPTION

The READDIR operation retrieves a variable number of entries from a filesystem directory and returns client requested attributes for each entry along with information to allow the client to request additional directory entries in a subsequent READDIR.

The arguments contain a cookie value that represents where the READDIR should start within the directory. A value of 0 (zero) for the cookie is used to start reading at the beginning of the directory. For subsequent READDIR requests, the client specifies a cookie value that is provided by the server on a previous READDIR request.

The cookieverf value should be set to 0 (zero) when the cookie value is 0 (zero) (first directory read). On subsequent requests, it should be a cookieverf as returned by the server. The cookieverf must match that returned by the READDIR in which the cookie was acquired. If the server determines that the cookieverf is no longer valid for the directory, the error NFS4ERR_NOT_SAME must be returned.

The dircount portion of the argument is a hint of the maximum number of bytes of directory information that should be returned. This value represents the length of the names of the directory entries and the cookie value for these entries. This length represents the XDR encoding of the data (names and cookies) and not the length in the native format of the server.

The maxcount value of the argument is the maximum number of bytes for the result. This maximum size represents all of the data being returned within the READDIR4resok structure and includes the XDR overhead. The server may return less data. If the server is unable to return a single directory entry within the maxcount limit, the error NFS4ERR_TOOSMALL will be returned to the client.

Finally, attr_request represents the list of attributes to be returned for each directory entry supplied by the server.

On successful return, the server's response will provide a list of directory entries. Each of these entries contains the name of the directory entry, a cookie value for that entry, and the associated attributes as requested. The "eof" flag has a value of TRUE if there are no more entries in the directory.

The cookie value is only meaningful to the server and is used as a "bookmark" for the directory entry. As mentioned, this cookie is used by the client for subsequent READDIR operations so that it may continue reading a directory. The cookie is similar in concept to a

READ offset but should not be interpreted as such by the client. Ideally, the cookie value should not change if the directory is modified since the client may be caching these values.

In some cases, the server may encounter an error while obtaining the attributes for a directory entry. Instead of returning an error for the entire READDIR operation, the server can instead return the attribute 'fattr4_rdattr_error'. With this, the server is able to communicate the failure to the client and not fail the entire operation in the instance of what might be a transient failure. Obviously, the client must request the fattr4_rdattr_error attribute for this method to work properly. If the client does not request the attribute, the server has no choice but to return failure for the entire READDIR operation.

For some filesystem environments, the directory entries "." and ".." have special meaning and in other environments, they may not. If the server supports these special entries within a directory, they should not be returned to the client as part of the READDIR response. To enable some client environments, the cookie values of 0, 1, and 2 are to be considered reserved. Note that the UNIX client will use these values when combining the server's response and local representations to enable a fully formed UNIX directory presentation to the application.

For READDIR arguments, cookie values of 1 and 2 SHOULD NOT be used and for READDIR results cookie values of 0, 1, and 2 MUST NOT be returned.

On success, the current filehandle retains its value.

15.26.5. IMPLEMENTATION

The server's filesystem directory representations can differ greatly. A client's programming interfaces may also be bound to the local operating environment in a way that does not translate well into the NFS protocol. Therefore the use of the dircount and maxcount fields are provided to allow the client the ability to provide guidelines to the server. If the client is aggressive about attribute collection during a READDIR, the server has an idea of how to limit the encoded response. The dircount field provides a hint on the number of entries based solely on the names of the directory entries. Since it is a hint, it may be possible that a dircount value is zero. In this case, the server is free to ignore the dircount value and return directory information based on the specified maxcount value.

The cookieverf may be used by the server to help manage cookie values that may become stale. It should be a rare occurrence that a server

is unable to continue properly reading a directory with the provided cookie/cookieverf pair. The server should make every effort to avoid this condition since the application at the client may not be able to properly handle this type of failure.

The use of the cookieverf will also protect the client from using READDIR cookie values that may be stale. For example, if the file system has been migrated, the server may or may not be able to use the same cookie values to service READDIR as the previous server used. With the client providing the cookieverf, the server is able to provide the appropriate response to the client. This prevents the case where the server may accept a cookie value but the underlying directory has changed and the response is invalid from the client's context of its previous READDIR.

Since some servers will not be returning "." and ".." entries as has been done with previous versions of the NFS protocol, the client that requires these entries be present in READDIR responses must fabricate them.

15.27. Operation 27: READLINK - Read Symbolic Link

15.27.1. SYNOPSIS

```
(cfh) -> linktext
```

15.27.2. ARGUMENT

```
/* CURRENT_FH: symlink */
void;
```

15.27.3. RESULT

```
struct READLINK4resok {
        linktext4       link;
};

union READLINK4res switch (nfsstat4 status) {
 case NFS4_OK:
         READLINK4resok resok4;
 default:
         void;
};
```

15.27.4. DESCRIPTION

READLINK reads the data associated with a symbolic link. The data is a UTF-8 string that is opaque to the server. That is, whether created by an NFS client or created locally on the server, the data in a symbolic link is not interpreted when created, but is simply stored.

On success, the current filehandle retains its value.

15.27.5. IMPLEMENTATION

A symbolic link is nominally a pointer to another file. The data is not necessarily interpreted by the server, just stored in the file. It is possible for a client implementation to store a path name that is not meaningful to the server operating system in a symbolic link. A READLINK operation returns the data to the client for interpretation. If different implementations want to share access to symbolic links, then they must agree on the interpretation of the data in the symbolic link.

The READLINK operation is only allowed on objects of type NF4LNK. The server should return the error, NFS4ERR_INVAL, if the object is not of type, NF4LNK.

15.28. Operation 28: REMOVE - Remove Filesystem Object

15.28.1. SYNOPSIS

```
(cfh), filename -> change_info
```

15.28.2. ARGUMENT

```
struct REMOVE4args {
        /* CURRENT_FH: directory */
        component4      target;
};
```

15.28.3. RESULT

```
struct REMOVE4resok {
        change_info4    cinfo;
};

union REMOVE4res switch (nfsstat4 status) {
 case NFS4_OK:
         REMOVE4resok   resok4;
 default:
         void;
};
```

15.28.4. DESCRIPTION

The REMOVE operation removes (deletes) a directory entry M named by filename from the directory corresponding to the current filehandle. If the entry in the directory was the last reference to the corresponding filesystem object, the object may be destroyed.

For the directory where the filename was removed, the server returns change_info4 information in cinfo. With the atomic field of the change_info4 struct, the server will indicate if the before and after change attributes were obtained atomically with respect to the removal.

If the target is of zero length, NFS4ERR_INVAL will be returned. The target is also subject to the normal UTF-8, character support, and name checks. See Section 12.3 for further discussion.

On success, the current filehandle retains its value.

15.28.5. IMPLEMENTATION

NFSv3 required a different operator RMDIR for directory removal and REMOVE for non-directory removal. This allowed clients to skip checking the file type when being passed a non-directory delete system call (e.g., unlink() [40] in POSIX) to remove a directory, as well as the converse (e.g., a rmdir() on a non-directory) because they knew the server would check the file type. NFSv4 REMOVE can be used to delete any directory entry independent of its file type. The implementor of an NFSv4 client's entry points from the unlink() and rmdir() system calls should first check the file type against the types the system call is allowed to remove before issuing a REMOVE. Alternatively, the implementor can produce a COMPOUND call that includes a LOOKUP/VERIFY sequence to verify the file type before a REMOVE operation in the same COMPOUND call.

The concept of last reference is server specific. However, if the numlinks field in the previous attributes of the object had the value 1, the client should not rely on referring to the object via a filehandle. Likewise, the client should not rely on the resources (disk space, directory entry, and so on) formerly associated with the object becoming immediately available. Thus, if a client needs to be able to continue to access a file after using REMOVE to remove it, the client should take steps to make sure that the file will still be accessible. The usual mechanism used is to RENAME the file from its old name to a new hidden name.

If the server finds that the file is still open when the REMOVE arrives:

- The server SHOULD NOT delete the file's directory entry if the file was opened with OPEN4_SHARE_DENY_WRITE or OPEN4_SHARE_DENY_BOTH.

- If the file was not opened with OPEN4_SHARE_DENY_WRITE or OPEN4_SHARE_DENY_BOTH, the server SHOULD delete the file's directory entry. However, until last CLOSE of the file, the server MAY continue to allow access to the file via its filehandle.

15.29. Operation 29: RENAME - Rename Directory Entry

15.29.1. SYNOPSIS

```
(sfh), oldname, (cfh), newname -> source_cinfo, target_cinfo
```

15.29.2. ARGUMENT

```
struct RENAME4args {
        /* SAVED_FH: source directory */
        component4      oldname;
        /* CURRENT_FH: target directory */
        component4      newname;
};
```

15.29.3. RESULT

```
struct RENAME4resok {
        change_info4    source_cinfo;
        change_info4    target_cinfo;
};

union RENAME4res switch (nfsstat4 status) {
 case NFS4_OK:
        RENAME4resok    resok4;
 default:
        void;
};
```

15.29.4. DESCRIPTION

The RENAME operation renames the object identified by oldname in the source directory corresponding to the saved filehandle, as set by the SAVEFH operation, to newname in the target directory corresponding to the current filehandle. The operation is required to be atomic to the client. Source and target directories must reside on the same filesystem on the server. On success, the current filehandle will continue to be the target directory.

If the target directory already contains an entry with the name, newname, the source object must be compatible with the target: either both are non-directories or both are directories and the target must be empty. If compatible, the existing target is removed before the rename occurs (See Section 15.28 for client and server actions whenever a target is removed). If they are not compatible or if the target is a directory but not empty, the server will return the error, NFS4ERR_EXIST.

If oldname and newname both refer to the same file (they might be hard links of each other), then RENAME should perform no action and return success.

For both directories involved in the RENAME, the server returns change_info4 information. With the atomic field of the change_info4 struct, the server will indicate if the before and after change attributes were obtained atomically with respect to the rename.

If the oldname refers to a named attribute and the saved and current filehandles refer to different filesystem objects, the server will return NFS4ERR_XDEV just as if the saved and current filehandles represented directories on different filesystems.

If the oldname or newname is of zero length, NFS4ERR_INVAL will be returned. The oldname and newname are also subject to the normal UTF-8, character support, and name checks. See Section 12.3 for further discussion.

15.29.5. IMPLEMENTATION

The RENAME operation must be atomic to the client. The statement "source and target directories must reside on the same filesystem on the server" means that the fsid fields in the attributes for the directories are the same. If they reside on different filesystems, the error, NFS4ERR_XDEV, is returned.

Based on the value of the fh_expire_type attribute for the object, the filehandle may or may not expire on a RENAME. However, server implementors are strongly encouraged to attempt to keep filehandles from expiring in this fashion.

On some servers, the file names "." and ".." are illegal as either oldname or newname, and will result in the error NFS4ERR_BADNAME. In addition, on many servers the case of oldname or newname being an alias for the source directory will be checked for. Such servers will return the error NFS4ERR_INVAL in these cases.

If either of the source or target filehandles are not directories, the server will return NFS4ERR_NOTDIR.

15.30. Operation 30: RENEW - Renew a Lease

15.30.1. SYNOPSIS

```
clientid -> ()
```

15.30.2. ARGUMENT

```
struct RENEW4args {
        clientid4       clientid;
};
```

15.30.3. RESULT

```
struct RENEW4res {
        nfsstat4        status;
};
```

15.30.4. DESCRIPTION

The RENEW operation is used by the client to renew leases which it currently holds at a server. In processing the RENEW request, the server renews all leases associated with the client. The associated leases are determined by the clientid provided via the SETCLIENTID operation.

15.30.5. IMPLEMENTATION

When the client holds delegations, it needs to use RENEW to detect when the server has determined that the callback path is down. When the server has made such a determination, only the RENEW operation will renew the lease on delegations. If the server determines the callback path is down, it returns NFS4ERR_CB_PATH_DOWN. Even though it returns NFS4ERR_CB_PATH_DOWN, the server MUST renew the lease on the byte-range locks and share reservations that the client has established on the server. If for some reason the lock and share reservation lease cannot be renewed, then the server MUST return an error other than NFS4ERR_CB_PATH_DOWN, even if the callback path is also down. In the event that the server has conditions such that is could return either NFS4ERR_CB_PATH_DOWN or NFS4ERR_LEASE_MOVED, NFS4ERR_LEASE_MOVED MUST be handled first.

The client that issues RENEW MUST choose the principal, RPC security flavor, and if applicable, GSS-API mechanism and service via one of the following algorithms:

- The client uses the same principal, RPC security flavor -- and if the flavor was RPCSEC_GSS -- the same mechanism and service that was used when the client id was established via SETCLIENTID_CONFIRM.

- The client uses any principal, RPC security flavor mechanism and service combination that currently has an OPEN file on the server. I.e., the same principal had a successful OPEN operation, the file is still open by that principal, and the flavor, mechanism, and service of RENEW match that of the previous OPEN.

The server MUST reject a RENEW that does not use one the aforementioned algorithms, with the error NFS4ERR_ACCESS.

15.31. Operation 31: RESTOREFH - Restore Saved Filehandle

15.31.1. SYNOPSIS

(sfh) -> (cfh)

15.31.2. ARGUMENT

```
/* SAVED_FH: */
void;
```

15.31.3. RESULT

```
struct RESTOREFH4res {
        /* CURRENT_FH: value of saved fh */
        nfsstat4        status;
};
```

15.31.4. DESCRIPTION

Set the current filehandle to the value in the saved filehandle. If there is no saved filehandle then return the error NFS4ERR_RESTOREFH.

15.31.5. IMPLEMENTATION

Operations like OPEN and LOOKUP use the current filehandle to represent a directory and replace it with a new filehandle. Assuming the previous filehandle was saved with a SAVEFH operator, the previous filehandle can be restored as the current filehandle. This is commonly used to obtain post-operation attributes for the directory, e.g.,

```
PUTFH (directory filehandle)
SAVEFH
GETATTR attrbits     (pre-op dir attrs)
CREATE optbits "foo" attrs
GETATTR attrbits     (file attributes)
RESTOREFH
GETATTR attrbits     (post-op dir attrs)
```

15.32. Operation 32: SAVEFH - Save Current Filehandle

15.32.1. SYNOPSIS

```
(cfh) -> (sfh)
```

15.32.2. ARGUMENT

```
/* CURRENT_FH: */
void;
```

15.32.3. RESULT

```
struct SAVEFH4res {
        /* SAVED_FH: value of current fh */
        nfsstat4        status;
};
```

15.32.4. DESCRIPTION

Save the current filehandle. If a previous filehandle was saved then it is no longer accessible. The saved filehandle can be restored as the current filehandle with the RESTOREFH operator.

On success, the current filehandle retains its value.

15.32.5. IMPLEMENTATION

15.33. Operation 33: SECINFO - Obtain Available Security

15.33.1. SYNOPSIS

```
  (cfh), name -> { secinfo }
```

15.33.2. ARGUMENT

```
struct SECINFO4args {
        /* CURRENT_FH: directory */
        component4      name;
};
```

15.33.3. RESULT

```
/*
 * From RFC 2203
 */
enum rpc_gss_svc_t {
        RPC_GSS_SVC_NONE        = 1,
        RPC_GSS_SVC_INTEGRITY   = 2,
        RPC_GSS_SVC_PRIVACY     = 3
};

struct rpcsec_gss_info {
        sec_oid4        oid;
        qop4            qop;
        rpc_gss_svc_t   service;
};

/* RPCSEC_GSS has a value of '6' - See RFC 2203 */
union secinfo4 switch (uint32_t flavor) {
 case RPCSEC_GSS:
         rpcsec_gss_info        flavor_info;
 default:
         void;
};

typedef secinfo4 SECINFO4resok<>;

union SECINFO4res switch (nfsstat4 status) {
 case NFS4_OK:
         SECINFO4resok resok4;
 default:
         void;
};
```

15.33.4. DESCRIPTION

The SECINFO operation is used by the client to obtain a list of valid RPC authentication flavors for a specific directory filehandle, file name pair. SECINFO should apply the same access methodology used for LOOKUP when evaluating the name. Therefore, if the requester does not have the appropriate access to LOOKUP the name then SECINFO must behave the same way and return NFS4ERR_ACCESS.

The result will contain an array which represents the security mechanisms available, with an order corresponding to server's preferences, the most preferred being first in the array. The client is free to pick whatever security mechanism it both desires and

supports, or to pick in the server's preference order the first one it supports. The array entries are represented by the secinfo4 structure. The field 'flavor' will contain a value of AUTH_NONE, AUTH_SYS (as defined in [4]), or RPCSEC_GSS (as defined in [5]).

For the flavors AUTH_NONE and AUTH_SYS, no additional security information is returned. For a return value of RPCSEC_GSS, a security triple is returned that contains the mechanism object id (as defined in [6]), the quality of protection (as defined in [6]) and the service type (as defined in [5]). It is possible for SECINFO to return multiple entries with flavor equal to RPCSEC_GSS with different security triple values.

On success, the current filehandle retains its value.

If the name has a length of 0 (zero), or if name does not obey the UTF-8 definition, the error NFS4ERR_INVAL will be returned.

15.33.5. IMPLEMENTATION

The SECINFO operation is expected to be used by the NFS client when the error value of NFS4ERR_WRONGSEC is returned from another NFS operation. This signifies to the client that the server's security policy is different from what the client is currently using. At this point, the client is expected to obtain a list of possible security flavors and choose what best suits its policies.

As mentioned, the server's security policies will determine when a client request receives NFS4ERR_WRONGSEC. The operations which may receive this error are: LINK, LOOKUP, LOOKUPP, OPEN, PUTFH, PUTPUBFH, PUTROOTFH, RENAME, RESTOREFH, and indirectly READDIR. LINK and RENAME will only receive this error if the security used for the operation is inappropriate for saved filehandle. With the exception of READDIR, these operations represent the point at which the client can instantiate a filehandle into the "current filehandle" at the server. The filehandle is either provided by the client (PUTFH, PUTPUBFH, PUTROOTFH) or generated as a result of a name to filehandle translation (LOOKUP and OPEN). RESTOREFH is different because the filehandle is a result of a previous SAVEFH. Even though the filehandle, for RESTOREFH, might have previously passed the server's inspection for a security match, the server will check it again on RESTOREFH to ensure that the security policy has not changed.

If the client wants to resolve an error return of NFS4ERR_WRONGSEC, the following will occur:

- For LOOKUP and OPEN, the client will use SECINFO with the same current filehandle and name as provided in the original LOOKUP or

OPEN to enumerate the available security triples.

- For LINK, PUTFH, RENAME, and RESTOREFH, the client will use SECINFO and provide the parent directory filehandle and object name which corresponds to the filehandle originally provided by the PUTFH RESTOREFH, or for LINK and RENAME, the SAVEFH.

- For LOOKUPP, PUTROOTFH and PUTPUBFH, the client will be unable to use the SECINFO operation since SECINFO requires a current filehandle and none exist for these two operations. Therefore, the client must iterate through the security triples available at the client and reattempt the PUTROOTFH or PUTPUBFH operation. In the unfortunate event none of the MANDATORY security triples are supported by the client and server, the client SHOULD try using others that support integrity. Failing that, the client can try using AUTH_NONE, but because such forms lack integrity checks, this puts the client at risk. Nonetheless, the server SHOULD allow the client to use whatever security form the client requests and the server supports, since the risks of doing so are on the client.

The READDIR operation will not directly return the NFS4ERR_WRONGSEC error. However, if the READDIR request included a request for attributes, it is possible that the READDIR request's security triple does not match that of a directory entry. If this is the case and the client has requested the rdattr_error attribute, the server will return the NFS4ERR_WRONGSEC error in rdattr_error for the entry.

Note that a server MAY use the AUTH_NONE flavor to signify that the client is allowed to attempt to use authentication flavors that are not explicitly listed in the SECINFO results. Instead of using a listed flavor, the client might then, for instance opt to use an otherwise unlisted RPCSEC_GSS mechanism instead of AUTH_NONE. It may wish to do so in order to meet an application requirement for data integrity or privacy. In choosing to use an unlisted flavor, the client SHOULD always be prepared to handle a failure by falling back to using AUTH_NONE or another listed flavor. It MUST NOT assume that identity mapping is supported, and should be prepared for the fact that its identity is squashed.

See Section 17 for a discussion on the recommendations for security flavor used by SECINFO.

15.34. Operation 34: SETATTR - Set Attributes

15.34.1. SYNOPSIS

(cfh), stateid, attrmask, attr_vals -> attrsset

15.34.2. ARGUMENT

```
struct SETATTR4args {
        /* CURRENT_FH: target object */
        stateid4        stateid;
        fattr4          obj_attributes;
};
```

15.34.3. RESULT

```
struct SETATTR4res {
        nfsstat4        status;
        bitmap4         attrsset;
};
```

15.34.4. DESCRIPTION

The SETATTR operation changes one or more of the attributes of a filesystem object. The new attributes are specified with a bitmap and the attributes that follow the bitmap in bit order.

The stateid argument for SETATTR is used to provide byte-range locking context that is necessary for SETATTR requests that set the size attribute. Since setting the size attribute modifies the file's data, it has the same locking requirements as a corresponding WRITE. Any SETATTR that sets the size attribute is incompatible with a share reservation that specifies OPEN4_SHARE_DENY_WRITE. The area between the old end-of-file and the new end-of-file is considered to be modified just as would have been the case had the area in question been specified as the target of WRITE, for the purpose of checking conflicts with byte-range locks, for those cases in which a server is implementing mandatory byte-range locking behavior. A valid stateid SHOULD always be specified. When the file size attribute is not set, the special stateid consisting of all bits zero MAY be passed.

On either success or failure of the operation, the server will return the attrsset bitmask to represent what (if any) attributes were successfully set. The attrsset in the response is a subset of the bitmap4 that is part of the obj_attributes in the argument.

On success, the current filehandle retains its value.

15.34.5. IMPLEMENTATION

If the request specifies the owner attribute to be set, the server SHOULD allow the operation to succeed if the current owner of the

object matches the value specified in the request. Some servers may be implemented in a way as to prohibit the setting of the owner attribute unless the requester has privilege to do so. If the server is lenient in this one case of matching owner values, the client implementation may be simplified in cases of creation of an object (e.g., an exclusive create via OPEN) followed by a SETATTR.

The file size attribute is used to request changes to the size of a file. A value of zero causes the file to be truncated, a value less than the current size of the file causes data from new size to the end of the file to be discarded, and a size greater than the current size of the file causes logically zeroed data bytes to be added to the end of the file. Servers are free to implement this using holes or actual zero data bytes. Clients should not make any assumptions regarding a server's implementation of this feature, beyond that the bytes returned will be zeroed. Servers MUST support extending the file size via SETATTR.

SETATTR is not guaranteed atomic. A failed SETATTR may partially change a file's attributes, hence the reason why the reply always includes the status and the list of attributes that were set.

If the object whose attributes are being changed has a file delegation that is held by a client other than the one doing the SETATTR, the delegation(s) must be recalled, and the operation cannot proceed to actually change an attribute until each such delegation is returned or revoked. In all cases in which delegations are recalled, the server is likely to return one or more NFS4ERR_DELAY errors while the delegation(s) remains outstanding, although it might not do that if the delegations are returned quickly.

Changing the size of a file with SETATTR indirectly changes the time_modify and change attributes. A client must account for this as size changes can result in data deletion.

The attributes time_access_set and time_modify_set are write-only attributes constructed as a switched union so the client can direct the server in setting the time values. If the switched union specifies SET_TO_CLIENT_TIME4, the client has provided an nfstime4 to be used for the operation. If the switch union does not specify SET_TO_CLIENT_TIME4, the server is to use its current time for the SETATTR operation.

If server and client times differ, programs that compare client time to file times can break. A time maintenance protocol should be used to limit client/server time skew.

Use of a COMPOUND containing a VERIFY operation specifying only the

change attribute, immediately followed by a SETATTR, provides a means whereby a client may specify a request that emulates the functionality of the SETATTR guard mechanism of NFSv3. Since the function of the guard mechanism is to avoid changes to the file attributes based on stale information, delays between checking of the guard condition and the setting of the attributes have the potential to compromise this function, as would the corresponding delay in the NFSv4 emulation. Therefore, NFSv4 servers should take care to avoid such delays, to the degree possible, when executing such a request.

If the server does not support an attribute as requested by the client, the server should return NFS4ERR_ATTRNOTSUPP.

A mask of the attributes actually set is returned by SETATTR in all cases. That mask MUST NOT include attribute bits not requested to be set by the client. If the attribute masks in the request and reply are equal, the status field in the reply MUST be NFS4_OK.

15.35. Operation 35: SETCLIENTID - Negotiate Client ID

15.35.1. SYNOPSIS

client, callback, callback_ident -> clientid, setclientid_confirm

15.35.2. ARGUMENT

```
struct SETCLIENTID4args {
        nfs_client_id4  client;
        cb_client4      callback;
        uint32_t        callback_ident;
};
```

15.35.3. RESULT

```
struct SETCLIENTID4resok {
        clientid4       clientid;
        verifier4       setclientid_confirm;
};

union SETCLIENTID4res switch (nfsstat4 status) {
 case NFS4_OK:
         SETCLIENTID4resok      resok4;
 case NFS4ERR_CLID_INUSE:
         clientaddr4    client_using;
 default:
         void;
};
```

15.35.4. DESCRIPTION

The client uses the SETCLIENTID operation to notify the server of its intention to use a particular client identifier, callback, and callback_ident for subsequent requests that entail creating lock, share reservation, and delegation state on the server. Upon successful completion the server will return a shorthand client ID which, if confirmed via a separate step, will be used in subsequent file locking and file open requests. Confirmation of the client ID must be done via the SETCLIENTID_CONFIRM operation to return the client ID and setclientid_confirm values, as verifiers, to the server. The reason why two verifiers are necessary is that it is possible to use SETCLIENTID and SETCLIENTID_CONFIRM to modify the callback and callback_ident information but not the shorthand client ID. In that event, the setclientid_confirm value is effectively the only verifier.

The callback information provided in this operation will be used if the client is provided an open delegation at a future point. Therefore, the client must correctly reflect the program and port numbers for the callback program at the time SETCLIENTID is used.

The callback_ident value is used by the server on the callback. The client can leverage the callback_ident to eliminate the need for more than one callback RPC program number, while still being able to determine which server is initiating the callback.

15.35.5. IMPLEMENTATION

To understand how to implement SETCLIENTID, make the following notations. Let:

x be the value of the client.id subfield of the SETCLIENTID4args structure.

v be the value of the client.verifier subfield of the SETCLIENTID4args structure.

c be the value of the client ID field returned in the SETCLIENTID4resok structure.

k represent the value combination of the fields callback and callback_ident fields of the SETCLIENTID4args structure.

s be the setclientid_confirm value returned in the SETCLIENTID4resok structure.

{ v, x, c, k, s } be a quintuple for a client record. A client record is confirmed if there has been a SETCLIENTID_CONFIRM operation to confirm it. Otherwise it is unconfirmed. An unconfirmed record is established by a SETCLIENTID call.

Since SETCLIENTID is a non-idempotent operation, let us assume that the server is implementing the duplicate request cache (DRC).

When the server gets a SETCLIENTID { v, x, k } request, it processes it in the following manner.

- It first looks up the request in the DRC. If there is a hit, it returns the result cached in the DRC. The server does NOT remove client state (locks, shares, delegations) nor does it modify any recorded callback and callback_ident information for client { x }.

  For any DRC miss, the server takes the client id string x, and searches for client records for x that the server may have recorded from previous SETCLIENTID calls. For any confirmed record with the same id string x, if the recorded principal does not match that of SETCLIENTID call, then the server returns a NFS4ERR_CLID_INUSE error.

  For brevity of discussion, the remaining description of the processing assumes that there was a DRC miss, and that where the server has previously recorded a confirmed record for client x, the aforementioned principal check has successfully passed.

- The server checks if it has recorded a confirmed record for { v, x, c, l, s }, where l may or may not equal k. If so, and since the id verifier v of the request matches that which is confirmed and recorded, the server treats this as a probable callback information update and records an unconfirmed { v, x, c, k, t }

and leaves the confirmed { v, x, c, l, s } in place, such that t != s. It does not matter if k equals l or not. Any pre-existing unconfirmed { v, x, c, *, * } is removed.

The server returns { c, t }. It is indeed returning the old clientid4 value c, because the client apparently only wants to update callback value k to value l. It's possible this request is one from the Byzantine router that has stale callback information, but this is not a problem. The callback information update is only confirmed if followed up by a SETCLIENTID_CONFIRM { c, t }.

The server awaits confirmation of k via SETCLIENTID_CONFIRM { c, t }.

The server does NOT remove client (lock/share/delegation) state for x.

- The server has previously recorded a confirmed { u, x, c, l, s } record such that v != u, l may or may not equal k, and has not recorded any unconfirmed { *, x, *, *, * } record for x. The server records an unconfirmed { v, x, d, k, t } (d != c, t != s).

  The server returns { d, t }.

  The server awaits confirmation of { d, k } via SETCLIENTID_CONFIRM { d, t }.

  The server does NOT remove client (lock/share/delegation) state for x.

- The server has previously recorded a confirmed { u, x, c, l, s } record such that v != u, l may or may not equal k, and recorded an unconfirmed { w, x, d, m, t } record such that c != d, t != s, m may or may not equal k, m may or may not equal l, and k may or may not equal l. Whether w == v or w != v makes no difference. The server simply removes the unconfirmed { w, x, d, m, t } record and replaces it with an unconfirmed { v, x, e, k, r } record, such that e != d, e != c, r != t, r != s.

  The server returns { e, r }.

  The server awaits confirmation of { e, k } via SETCLIENTID_CONFIRM { e, r }.

  The server does NOT remove client (lock/share/delegation) state for x.

- The server has no confirmed { *, x, *, *, * } for x. It may or may not have recorded an unconfirmed { u, x, c, l, s }, where l may or may not equal k, and u may or may not equal v. Any unconfirmed record { u, x, c, l, * }, regardless whether u == v or l == k, is replaced with an unconfirmed record { v, x, d, k, t } where d != c, t != s.

  The server returns { d, t }.

  The server awaits confirmation of { d, k } via SETCLIENTID_CONFIRM { d, t }. The server does NOT remove client (lock/share/delegation) state for x.

The server generates the clientid and setclientid_confirm values and must take care to ensure that these values are extremely unlikely to ever be regenerated.

15.36. Operation 36: SETCLIENTID_CONFIRM - Confirm Client ID

15.36.1. SYNOPSIS

```
clientid, setclientid_confirm -> -
```

15.36.2. ARGUMENT

```
struct SETCLIENTID_CONFIRM4args {
        clientid4       clientid;
        verifier4       setclientid_confirm;
};
```

15.36.3. RESULT

```
struct SETCLIENTID_CONFIRM4res {
        nfsstat4        status;
};
```

15.36.4. DESCRIPTION

This operation is used by the client to confirm the results from a previous call to SETCLIENTID. The client provides the server supplied (from a SETCLIENTID response) client ID. The server responds with a simple status of success or failure.

15.36.5. IMPLEMENTATION

The client must use the SETCLIENTID_CONFIRM operation to confirm the following two distinct cases:

- The client's use of a new shorthand client identifier (as returned from the server in the response to SETCLIENTID), a new callback value (as specified in the arguments to SETCLIENTID) and a new callback_ident (as specified in the arguments to SETCLIENTID) value. The client's use of SETCLIENTID_CONFIRM in this case also confirms the removal of any of the client's previous relevant leased state. Relevant leased client state includes byte-range locks, share reservations, and where the server does not support the CLAIM_DELEGATE_PREV claim type, delegations. If the server supports CLAIM_DELEGATE_PREV, then SETCLIENTID_CONFIRM MUST NOT remove delegations for this client; relevant leased client state would then just include byte-range locks and share reservations.

- The client's re-use of an old, previously confirmed, shorthand client identifier, a new callback value, and a new callback_ident value. The client's use of SETCLIENTID_CONFIRM in this case MUST NOT result in the removal of any previous leased state (locks, share reservations, and delegations)

We use the same notation and definitions for v, x, c, k, s, and unconfirmed and confirmed client records as introduced in the description of the SETCLIENTID operation. The arguments to SETCLIENTID_CONFIRM are indicated by the notation { c, s }, where c is a value of type clientid4, and s is a value of type verifier4 corresponding to the setclientid_confirm field.

As with SETCLIENTID, SETCLIENTID_CONFIRM is a non-idempotent operation, and we assume that the server is implementing the duplicate request cache (DRC).

When the server gets a SETCLIENTID_CONFIRM { c, s } request, it processes it in the following manner.

- It first looks up the request in the DRC. If there is a hit, it returns the result cached in the DRC. The server does not remove any relevant leased client state nor does it modify any recorded callback and callback_ident information for client { x } as represented by the shorthand value c.

For a DRC miss, the server checks for client records that match the shorthand value c. The processing cases are as follows:

- The server has recorded an unconfirmed { v, x, c, k, s } record and a confirmed { v, x, c, l, t } record, such that s != t. If the principals of the records do not match that of the SETCLIENTID_CONFIRM, the server returns NFS4ERR_CLID_INUSE, and no relevant leased client state is removed and no recorded callback and callback_ident information for client { x } is changed. Otherwise, the confirmed { v, x, c, l, t } record is removed and the unconfirmed { v, x, c, k, s } is marked as confirmed, thereby modifying recorded and confirmed callback and callback_ident information for client { x }.

  The server does not remove any relevant leased client state.

  The server returns NFS4_OK.

- The server has not recorded an unconfirmed { v, x, c, *, * } and has recorded a confirmed { v, x, c, *, s }. If the principals of the record and of SETCLIENTID_CONFIRM do not match, the server returns NFS4ERR_CLID_INUSE without removing any relevant leased client state and without changing recorded callback and callback_ident values for client { x }.

  If the principals match, then what has likely happened is that the client never got the response from the SETCLIENTID_CONFIRM, and the DRC entry has been purged. Whatever the scenario, since the principals match, as well as { c, s } matching a confirmed record, the server leaves client x's relevant leased client state intact, leaves its callback and callback_ident values unmodified, and returns NFS4_OK.

- The server has not recorded a confirmed { *, *, c, *, * }, and has recorded an unconfirmed { *, x, c, k, s }. Even if this is a retry from client, nonetheless the client's first SETCLIENTID_CONFIRM attempt was not received by the server. Retry or not, the server doesn't know, but it processes it as if were a first try. If the principal of the unconfirmed { *, x, c, k, s } record mismatches that of the SETCLIENTID_CONFIRM request the server returns NFS4ERR_CLID_INUSE without removing any relevant leased client state.

  Otherwise, the server records a confirmed { *, x, c, k, s }. If there is also a confirmed { *, x, d, *, t }, the server MUST remove the client x's relevant leased client state, and overwrite the callback state with k. The confirmed record { *, x, d, *, t } is removed.

  Server returns NFS4_OK.

- The server has no record of a confirmed or unconfirmed { *, *, c, *, s }. The server returns NFS4ERR_STALE_CLIENTID. The server does not remove any relevant leased client state, nor does it modify any recorded callback and callback_ident information for any client.

The server needs to cache unconfirmed { v, x, c, k, s } client records and await for some time their confirmation. As should be clear from the record processing discussions for SETCLIENTID and SETCLIENTID_CONFIRM, there are cases where the server does not deterministically remove unconfirmed client records. To avoid running out of resources, the server is not required to hold unconfirmed records indefinitely. One strategy the server might use is to set a limit on how many unconfirmed client records it will maintain, and then when the limit would be exceeded, remove the oldest record. Another strategy might be to remove an unconfirmed record when some amount of time has elapsed. The choice of the amount of time is fairly arbitrary but it is surely no higher than the server's lease time period. Consider that leases need to be renewed before the lease time expires via an operation from the client. If the client cannot issue a SETCLIENTID_CONFIRM after a SETCLIENTID before a period of time equal to that of a lease expires, then the client is unlikely to be able maintain state on the server during steady state operation.

If the client does send a SETCLIENTID_CONFIRM for an unconfirmed record that the server has already deleted, the client will get NFS4ERR_STALE_CLIENTID back. If so, the client should then start over, and send SETCLIENTID to reestablish an unconfirmed client record and get back an unconfirmed client ID and setclientid_confirm verifier. The client should then send the SETCLIENTID_CONFIRM to confirm the client ID.

SETCLIENTID_CONFIRM does not establish or renew a lease. However, if SETCLIENTID_CONFIRM removes relevant leased client state, and that state does not include existing delegations, the server MUST allow the client a period of time no less than the value of lease_time attribute, to reclaim, (via the CLAIM_DELEGATE_PREV claim type of the OPEN operation) its delegations before removing unreclaimed delegations.

15.37. Operation 37: VERIFY - Verify Same Attributes

15.37.1. SYNOPSIS

(cfh), fattr -> -

15.37.2. ARGUMENT

```
struct VERIFY4args {
        /* CURRENT_FH: object */
        fattr4          obj_attributes;
};
```

15.37.3. RESULT

```
struct VERIFY4res {
        nfsstat4        status;
};
```

15.37.4. DESCRIPTION

The VERIFY operation is used to verify that attributes have a value assumed by the client before proceeding with following operations in the compound request. If any of the attributes do not match then the error NFS4ERR_NOT_SAME must be returned. The current filehandle retains its value after successful completion of the operation.

15.37.5. IMPLEMENTATION

One possible use of the VERIFY operation is the following compound sequence. With this the client is attempting to verify that the file being removed will match what the client expects to be removed. This sequence can help prevent the unintended deletion of a file.

```
PUTFH (directory filehandle)
LOOKUP (file name)
VERIFY (filehandle == fh)
PUTFH (directory filehandle)
REMOVE (file name)
```

This sequence does not prevent a second client from removing and creating a new file in the middle of this sequence but it does help avoid the unintended result.

In the case that a recommended attribute is specified in the VERIFY operation and the server does not support that attribute for the filesystem object, the error NFS4ERR_ATTRNOTSUPP is returned to the client.

When the attribute rdattr_error or any write-only attribute (e.g., time_modify_set) is specified, the error NFS4ERR_INVAL is returned to the client.

15.38. Operation 38: WRITE - Write to File

15.38.1. SYNOPSIS

(cfh), stateid, offset, stable, data -> count, committed, writeverf

15.38.2. ARGUMENT

```
enum stable_how4 {
        UNSTABLE4       = 0,
        DATA_SYNC4      = 1,
        FILE_SYNC4      = 2
};

struct WRITE4args {
        /* CURRENT_FH: file */
        stateid4        stateid;
        offset4         offset;
        stable_how4     stable;
        opaque          data<>;
};
```

15.38.3. RESULT

```
struct WRITE4resok {
        count4          count;
        stable_how4     committed;
        verifier4       writeverf;
};

union WRITE4res switch (nfsstat4 status) {
 case NFS4_OK:
         WRITE4resok    resok4;
 default:
         void;
};
```

15.38.4. DESCRIPTION

The WRITE operation is used to write data to a regular file. The target file is specified by the current filehandle. The offset specifies the offset where the data should be written. An offset of 0 (zero) specifies that the write should start at the beginning of the file. The count, as encoded as part of the opaque data parameter, represents the number of bytes of data that are to be written. If the count is 0 (zero), the WRITE will succeed and return

a count of 0 (zero) subject to permissions checking. The server may choose to write fewer bytes than requested by the client.

Part of the write request is a specification of how the write is to be performed. The client specifies with the stable parameter the method of how the data is to be processed by the server. If stable is FILE_SYNC4, the server must commit the data written plus all filesystem metadata to stable storage before returning results. This corresponds to the NFS version 2 protocol semantics. Any other behavior constitutes a protocol violation. If stable is DATA_SYNC4, then the server must commit all of the data to stable storage and enough of the metadata to retrieve the data before returning. The server implementor is free to implement DATA_SYNC4 in the same fashion as FILE_SYNC4, but with a possible performance drop. If stable is UNSTABLE4, the server is free to commit any part of the data and the metadata to stable storage, including all or none, before returning a reply to the client. There is no guarantee whether or when any uncommitted data will subsequently be committed to stable storage. The only guarantees made by the server are that it will not destroy any data without changing the value of verf and that it will not commit the data and metadata at a level less than that requested by the client.

The stateid value for a WRITE request represents a value returned from a previous byte-range lock or share reservation request or the stateid associated with a delegation. The stateid is used by the server to verify that the associated share reservation and any byte-range locks are still valid and to update lease timeouts for the client.

Upon successful completion, the following results are returned. The count result is the number of bytes of data written to the file. The server may write fewer bytes than requested. If so, the actual number of bytes written starting at location, offset, is returned.

The server also returns an indication of the level of commitment of the data and metadata via committed. If the server committed all data and metadata to stable storage, committed should be set to FILE_SYNC4. If the level of commitment was at least as strong as DATA_SYNC4, then committed should be set to DATA_SYNC4. Otherwise, committed must be returned as UNSTABLE4. If stable was FILE4_SYNC, then committed must also be FILE_SYNC4: anything else constitutes a protocol violation. If stable was DATA_SYNC4, then committed may be FILE_SYNC4 or DATA_SYNC4: anything else constitutes a protocol violation. If stable was UNSTABLE4, then committed may be either FILE_SYNC4, DATA_SYNC4, or UNSTABLE4.

The final portion of the result is the write verifier. The write

verifier is a cookie that the client can use to determine whether the server has changed instance (boot) state between a call to WRITE and a subsequent call to either WRITE or COMMIT. This cookie must be consistent during a single instance of the NFSv4 protocol service and must be unique between instances of the NFSv4 protocol server, where uncommitted data may be lost.

If a client writes data to the server with the stable argument set to UNSTABLE4 and the reply yields a committed response of DATA_SYNC4 or UNSTABLE4, the client will follow up some time in the future with a COMMIT operation to synchronize outstanding asynchronous data and metadata with the server's stable storage, barring client error. It is possible that due to client crash or other error that a subsequent COMMIT will not be received by the server.

For a WRITE with a stateid value of all bits 0, the server MAY allow the WRITE to be serviced subject to mandatory file locks or the current share deny modes for the file. For a WRITE with a stateid value of all bits 1, the server MUST NOT allow the WRITE operation to bypass locking checks at the server and are treated exactly the same as if a stateid of all bits 0 were used.

On success, the current filehandle retains its value.

15.38.5. IMPLEMENTATION

It is possible for the server to write fewer bytes of data than requested by the client. In this case, the server should not return an error unless no data was written at all. If the server writes less than the number of bytes specified, the client should issue another WRITE to write the remaining data.

It is assumed that the act of writing data to a file will cause the time_modified of the file to be updated. However, the time_modified of the file should not be changed unless the contents of the file are changed. Thus, a WRITE request with count set to 0 should not cause the time_modified of the file to be updated.

The definition of stable storage has been historically a point of contention. The following expected properties of stable storage may help in resolving design issues in the implementation. Stable storage is persistent storage that survives:

1. Repeated power failures.

2. Hardware failures (of any board, power supply, etc.).

3. Repeated software crashes, including reboot cycle.

This definition does not address failure of the stable storage module itself.

The verifier is defined to allow a client to detect different instances of an NFSv4 protocol server over which cached, uncommitted data may be lost. In the most likely case, the verifier allows the client to detect server reboots. This information is required so that the client can safely determine whether the server could have lost cached data. If the server fails unexpectedly and the client has uncommitted data from previous WRITE requests (done with the stable argument set to UNSTABLE4 and in which the result committed was returned as UNSTABLE4 as well) it may not have flushed cached data to stable storage. The burden of recovery is on the client and the client will need to retransmit the data to the server.

A suggested verifier would be to use the time that the server was booted or the time the server was last started (if restarting the server without a reboot results in lost buffers).

The committed field in the results allows the client to do more effective caching. If the server is committing all WRITE requests to stable storage, then it should return with committed set to FILE_SYNC4, regardless of the value of the stable field in the arguments. A server that uses an NVRAM accelerator may choose to implement this policy. The client can use this to increase the effectiveness of the cache by discarding cached data that has already been committed on the server.

Some implementations may return NFS4ERR_NOSPC instead of NFS4ERR_DQUOT when a user's quota is exceeded. In the case that the current filehandle is a directory, the server will return NFS4ERR_ISDIR. If the current filehandle is not a regular file or a directory, the server will return NFS4ERR_INVAL.

If mandatory file locking is on for the file, and corresponding record of the data to be written file is read or write locked by an owner that is not associated with the stateid, the server will return NFS4ERR_LOCKED. If so, the client must check if the owner corresponding to the stateid used with the WRITE operation has a conflicting read lock that overlaps with the region that was to be written. If the stateid's owner has no conflicting read lock, then the client should try to get the appropriate write byte-range lock via the LOCK operation before re-attempting the WRITE. When the WRITE completes, the client should release the byte-range lock via LOCKU.

If the stateid's owner had a conflicting read lock, then the client has no choice but to return an error to the application that attempted the WRITE. The reason is that since the stateid's owner had a read lock, the server either attempted to temporarily effectively upgrade this read lock to a write lock, or the server has no upgrade capability. If the server attempted to upgrade the read lock and failed, it is pointless for the client to re-attempt the upgrade via the LOCK operation, because there might be another client also trying to upgrade. If two clients are blocked trying upgrade the same lock, the clients deadlock. If the server has no upgrade capability, then it is pointless to try a LOCK operation to upgrade.

15.39. Operation 39: RELEASE_LOCKOWNER - Release Lockowner State

15.39.1. SYNOPSIS

```
lock-owner -> ()
```

15.39.2. ARGUMENT

```
struct RELEASE_LOCKOWNER4args {
        lock_owner4     lock_owner;
};
```

15.39.3. RESULT

```
struct RELEASE_LOCKOWNER4res {
        nfsstat4        status;
};
```

15.39.4. DESCRIPTION

This operation is used to notify the server that the lock_owner is no longer in use by the client and that future client requests will not reference this lock_owner. This allows the server to release cached state related to the specified lock_owner. If file locks, associated with the lock_owner, are held at the server, the error NFS4ERR_LOCKS_HELD will be returned and no further action will be taken.

15.39.5. IMPLEMENTATION

The client may choose to use this operation to ease the amount of server state that is held. Information that can be released when a RELEASE_LOCKOWNER is done includes the specified lock-owner string, the seqid associated with the lock-owner, any saved reply for the

lock-owner, and any lock stateids associated with that lock-owner.

Depending on the behavior of applications at the client, it may be important for the client to use this operation since the server has certain obligations with respect to holding a reference to lock-owner-associated state as long as an associated file is open. Therefore, if the client knows for certain that the lock_owner will no longer be used, either to reference existing lock stateids associated with the lock-owner to create new ones, it should use RELEASE_LOCKOWNER.

15.40. Operation 10044: ILLEGAL - Illegal operation

15.40.1. SYNOPSIS

```
<null> -> ()
```

15.40.2. ARGUMENT

```
void;
```

15.40.3. RESULT

```
struct ILLEGAL4res {
        nfsstat4        status;
};
```

15.40.4. DESCRIPTION

This operation is a place holder for encoding a result to handle the case of the client sending an operation code within COMPOUND that is not supported. See Section 15.2.4 for more details.

The status field of ILLEGAL4res MUST be set to NFS4ERR_OP_ILLEGAL.

15.40.5. IMPLEMENTATION

A client will probably not send an operation with code OP_ILLEGAL but if it does, the response will be ILLEGAL4res just as it would be with any other invalid operation code. Note that if the server gets an illegal operation code that is not OP_ILLEGAL, and if the server checks for legal operation codes during the XDR decode phase, then the ILLEGAL4res would not be returned.

16. NFSv4 Callback Procedures

The procedures used for callbacks are defined in the following sections. In the interest of clarity, the terms "client" and "server" refer to NFS clients and servers, despite the fact that for an individual callback RPC, the sense of these terms would be precisely the opposite.

16.1. Procedure 0: CB_NULL - No Operation

16.1.1. SYNOPSIS

<null>

16.1.2. ARGUMENT

void;

16.1.3. RESULT

void;

16.1.4. DESCRIPTION

Standard NULL procedure. Void argument, void response. Even though there is no direct functionality associated with this procedure, the server will use CB_NULL to confirm the existence of a path for RPCs from server to client.

16.2. Procedure 1: CB_COMPOUND - Compound Operations

16.2.1. SYNOPSIS

compoundargs -> compoundres

16.2.2. ARGUMENT

```
enum nfs_cb_opnum4 {
        OP_CB_GETATTR           = 3,
        OP_CB_RECALL            = 4,
        OP_CB_ILLEGAL           = 10044
};
```

```
union nfs_cb_argop4 switch (unsigned argop) {
 case OP_CB_GETATTR:
      CB_GETATTR4args           opcbgetattr;
 case OP_CB_RECALL:
      CB_RECALL4args            opcbrecall;
 case OP_CB_ILLEGAL:            void;
};


struct CB_COMPOUND4args {
        comptag4        tag;
        uint32_t        minorversion;
        uint32_t        callback_ident;
        nfs_cb_argop4   argarray<>;
};
```

16.2.3. RESULT

```
union nfs_cb_resop4 switch (unsigned resop) {
 case OP_CB_GETATTR:    CB_GETATTR4res  opcbgetattr;
 case OP_CB_RECALL:     CB_RECALL4res   opcbrecall;
 case OP_CB_ILLEGAL:    CB_ILLEGAL4res  opcbillegal;
};


struct CB_COMPOUND4res {
        nfsstat4        status;
        comptag4        tag;
        nfs_cb_resop4   resarray<>;
};
```

16.2.4. DESCRIPTION

The CB_COMPOUND procedure is used to combine one or more of the callback procedures into a single RPC request. The main callback RPC program has two main procedures: CB_NULL and CB_COMPOUND. All other operations use the CB_COMPOUND procedure as a wrapper.

In the processing of the CB_COMPOUND procedure, the client may find that it does not have the available resources to execute any or all of the operations within the CB_COMPOUND sequence. In this case, the error NFS4ERR_RESOURCE will be returned for the particular operation within the CB_COMPOUND procedure where the resource exhaustion occurred. This assumes that all previous operations within the CB_COMPOUND sequence have been evaluated successfully.

Contained within the CB_COMPOUND results is a 'status' field. This status must be equivalent to the status of the last operation that

was executed within the CB_COMPOUND procedure. Therefore, if an operation incurred an error then the 'status' value will be the same error value as is being returned for the operation that failed.

For the definition of the "tag" field, see Section 15.2.

The value of callback_ident is supplied by the client during SETCLIENTID. The server must use the client supplied callback_ident during the CB_COMPOUND to allow the client to properly identify the server.

Illegal operation codes are handled in the same way as they are handled for the COMPOUND procedure.

16.2.5. IMPLEMENTATION

The CB_COMPOUND procedure is used to combine individual operations into a single RPC request. The client interprets each of the operations in turn. If an operation is executed by the client and the status of that operation is NFS4_OK, then the next operation in the CB_COMPOUND procedure is executed. The client continues this process until there are no more operations to be executed or one of the operations has a status value other than NFS4_OK.

16.2.6. Operation 3: CB_GETATTR - Get Attributes

16.2.6.1. SYNOPSIS

```
fh, attr_request -> attrmask, attr_vals
```

16.2.6.2. ARGUMENT

```
struct CB_GETATTR4args {
        nfs_fh4 fh;
        bitmap4 attr_request;
};
```

16.2.6.3. RESULT

```
struct CB_GETATTR4resok {
        fattr4  obj_attributes;
};

union CB_GETATTR4res switch (nfsstat4 status) {
 case NFS4_OK:
         CB_GETATTR4resok       resok4;
 default:
         void;
};
```

16.2.6.4. DESCRIPTION

The CB_GETATTR operation is used by the server to obtain the current modified state of a file that has been OPEN_DELEGATE_WRITE delegated. The attributes size and change are the only ones guaranteed to be serviced by the client. See Section 10.4.3 for a full description of how the client and server are to interact with the use of CB_GETATTR.

If the filehandle specified is not one for which the client holds a OPEN_DELEGATE_WRITE delegation, an NFS4ERR_BADHANDLE error is returned.

16.2.6.5. IMPLEMENTATION

The client returns attrmask bits and the associated attribute values only for the change attribute, and attributes that it may change (time_modify, and size).

16.2.7. Operation 4: CB_RECALL - Recall an Open Delegation

16.2.7.1. SYNOPSIS

```
  stateid, truncate, fh -> ()
```

16.2.7.2. ARGUMENT

```
struct CB_RECALL4args {
        stateid4        stateid;
        bool            truncate;
        nfs_fh4         fh;
};
```

16.2.7.3. RESULT

```
struct CB_RECALL4res {
        nfsstat4        status;
};
```

16.2.7.4. DESCRIPTION

The CB_RECALL operation is used to begin the process of recalling an open delegation and returning it to the server.

The truncate flag is used to optimize recall for a file which is about to be truncated to zero. When it is set, the client is freed of obligation to propagate modified data for the file to the server, since this data is irrelevant.

If the handle specified is not one for which the client holds an open delegation, an NFS4ERR_BADHANDLE error is returned.

If the stateid specified is not one corresponding to an open delegation for the file specified by the filehandle, an NFS4ERR_BAD_STATEID is returned.

16.2.7.5. IMPLEMENTATION

The client should reply to the callback immediately. Replying does not complete the recall except when an error was returned. The recall is not complete until the delegation is returned using a DELEGRETURN.

16.2.8. Operation 10044: CB_ILLEGAL - Illegal Callback Operation

16.2.8.1. SYNOPSIS

```
<null> -> ()
```

16.2.8.2. ARGUMENT

```
void;
```

16.2.8.3. RESULT

```
/*
 * CB_ILLEGAL: Response for illegal operation numbers
 */
struct CB_ILLEGAL4res {
        nfsstat4        status;
};
```

16.2.8.4. DESCRIPTION

This operation is a place-holder for encoding a result to handle the case of the client sending an operation code within COMPOUND that is not supported. See Section 15.2.4 for more details.

The status field of CB_ILLEGAL4res MUST be set to NFS4ERR_OP_ILLEGAL.

16.2.8.5. IMPLEMENTATION

A server will probably not send an operation with code OP_CB_ILLEGAL but if it does, the response will be CB_ILLEGAL4res just as it would be with any other invalid operation code. Note that if the client gets an illegal operation code that is not OP_ILLEGAL, and if the client checks for legal operation codes during the XDR decode phase, then the CB_ILLEGAL4res would not be returned.

17. Security Considerations

NFS has historically used a model where, from an authentication perspective, the client was the entire machine, or at least the source IP address of the machine. The NFS server relied on the NFS client to make the proper authentication of the end-user. The NFS server in turn shared its files only to specific clients, as identified by the client's source IP address. Given this model, the AUTH_SYS RPC security flavor simply identified the end-user using the client to the NFS server. When processing NFS responses, the client ensured that the responses came from the same IP address and port number that the request was sent to. While such a model is easy to implement and simple to deploy and use, it is certainly not a safe model. Thus, NFSv4 mandates that implementations support a security model that uses end to end authentication, where an end-user on a client mutually authenticates (via cryptographic schemes that do not expose passwords or keys in the clear on the network) to a principal on an NFS server. Consideration should also be given to the integrity and privacy of NFS requests and responses. The issues of end to end mutual authentication, integrity, and privacy are

discussed as part of Section 3.

When an NFSv4 mandated security model is used and a security principal or an NFSv4 name in user@dns_domain form needs to be translated to or from a local representation as described in Section 5.9, the translation SHOULD be done in a secure manner that preserves the integrity of the translation. For communication with a name service such as LDAP ([41]), this means employing a security service that uses authentication and data integrity. Kerberos and TLS ([42]) are examples of such a security service.

Note that being REQUIRED to implement does not mean REQUIRED to use; AUTH_SYS can be used by NFSv4 clients and servers. However, AUTH_SYS is merely an OPTIONAL security flavor in NFSv4, and so interoperability via AUTH_SYS is not assured.

For reasons of reduced administration overhead, better performance and/or reduction of CPU utilization, users of NFSv4 implementations may choose to not use security mechanisms that enable integrity protection on each remote procedure call and response. The use of mechanisms without integrity leaves the customer vulnerable to an attacker in between the NFS client and server that modifies the RPC request and/or the response. While implementations are free to provide the option to use weaker security mechanisms, there are two operations in particular that warrant the implementation overriding user choices.

The first such operation is SECINFO. It is recommended that the client issue the SECINFO call such that it is protected with a security flavor that has integrity protection, such as RPCSEC_GSS with a security triple that uses either rpc_gss_svc_integrity or rpc_gss_svc_privacy (rpc_gss_svc_privacy includes integrity protection) service. Without integrity protection encapsulating SECINFO and therefore its results, an attacker in the middle could modify results such that the client might select a weaker algorithm in the set allowed by server, making the client and/or server vulnerable to further attacks.

The second operation that should definitely use integrity protection is any GETATTR for the fs_locations attribute. The attack has two steps. First the attacker modifies the unprotected results of some operation to return NFS4ERR_MOVED. Second, when the client follows up with a GETATTR for the fs_locations attribute, the attacker modifies the results to cause the client migrate its traffic to a server controlled by the attacker.

Because the operations SETCLIENTID/SETCLIENTID_CONFIRM are responsible for the release of client state, it is imperative that

the principal used for these operations is checked against and match the previous use of these operations. See Section 9.1.1 for further discussion.

18. IANA Considerations

This section uses terms that are defined in [43].

18.1. Named Attribute Definitions

IANA will create a registry called the "NFSv4 Named Attribute Definitions Registry".

The NFSv4 protocol supports the association of a file with zero or more named attributes. The name space identifiers for these attributes are defined as string names. The protocol does not define the specific assignment of the name space for these file attributes. An IANA registry will promote interoperability where common interests exist. While application developers are allowed to define and use attributes as needed, they are encouraged to register the attributes with IANA.

Such registered named attributes are presumed to apply to all minor versions of NFSv4, including those defined subsequently to the registration. Where the named attribute is intended to be limited with regard to the minor versions for which they are not be used, the assignment in registry will clearly state the applicable limits.

All assignments to the registry are made on a First Come First Served basis, per section 4.1 of [43]. The policy for each assignment is Specification Required, per section 4.1 of [43].

Under the NFSv4 specification, the name of a named attribute can in theory be up to 2^32 - 1 bytes in length, but in practice NFSv4 clients and servers will be unable to a handle string that long. IANA should reject any assignment request with a named attribute that exceeds 128 UTF-8 characters. To give IESG the flexibility to set up bases of assignment of Experimental Use and Standards Action, the prefixes of "EXPE" and "STDS" are Reserved. The zero length named attribute name is Reserved.

The prefix "PRIV" is allocated for Private Use. A site that wants to make use of unregistered named attributes without risk of conflicting with an assignment in IANA's registry should use the prefix "PRIV" in all of its named attributes.

Because some NFSv4 clients and servers have case insensitive

semantics, the fifteen additional lower case and mixed case permutations of each of "EXPE", "PRIV", and "STDS", are Reserved (e.g. "expe", "expE", "exPe", etc. are Reserved). Similarly, IANA must not allow two assignments that would conflict if both named attributes were converted to a common case.

The registry of named attributes is a list of assignments, each containing three fields for each assignment.

1. A US-ASCII string name that is the actual name of the attribute. This name must be unique. This string name can be 1 to 128 UTF-8 characters long.

2. A reference to the specification of the named attribute. The reference can consume up to 256 bytes (or more if IANA permits).

3. The point of contact of the registrant. The point of contact can consume up to 256 bytes (or more if IANA permits).

18.1.1. Initial Registry

There is no initial registry.

18.1.2. Updating Registrations

The registrant is always permitted to update the point of contact field. To make any other change will require Expert Review or IESG Approval.

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Appendix B. RFC Editor Notes

[RFC Editor: please remove this section prior to publishing this document as an RFC]

[RFC Editor: prior to publishing this document as an RFC, please replace all occurrences of RFCNFSv4XDR with RFCxxxx where xxxx is the RFC number assigned to the XDR document.]

[RFC Editor: Please note that there is also a reference entry that needs to be modified for the companion document.]

Authors' Addresses

Thomas Haynes (editor)
NetApp
9110 E 66th St
Tulsa, OK 74133
USA

Phone: +1 918 307 1415
Email: thomas@netapp.com
URI: http://www.tulsalabs.com

David Noveck (editor)
EMC Corporation
228 South Street
Hopkinton, MA 01748
US

Phone: +1 508 249 5748
Email: david.noveck@emc.com